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OF THE

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NOTE.

The authors of the several papers contained in this volume are themselves accountable for all the statements and reasonings which they have offered. In these particulars the Society must not be considered as in any way responsible.

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MEMOIRS.

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M. = Memoirs. P. = Proceedings.

ERRATA.

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Vol. 64 : Part I.

MEMOIRS AND PROCEEDINGS

OF

THE MANCHESTER LITERARY & PHILOSOPHICAL SOCIETY, 1919-20.

CONTENTS.

MANCHESTER :

36, GEORGE STREET.

Price : Four Shillings.

February 28th, 1921.

I.—A Discussion of the Theorems of Lambert and Adams on Motion in Elliptic and Hyperbolic Orbits.

By L. V. Meadowcroft, B.A., M.Sc.

(Communicated by Professor Sydney Chapman, M.A., D.Sc., F.R.S.)
(Read Dec. 2nd, 1919. Received for Publication, Dec. 29th, 1919.)

The theorem of Lambert* on the motion of a planet in an elliptic orbit is usually enunciated as follows:—

"If t is the time of describing any arc P_1P_2 of an ellipse, and k is the chord of the arc, then $nt=(\phi_1-\sin\phi_1)-(\phi_2-\sin\phi_2)$, where

$$\sin\tfrac{1}{2}\phi_1=\tfrac{1}{2}\sqrt{\frac{r_1+r_2+k}{a}},\quad \sin\tfrac{1}{2}\phi_2=\tfrac{1}{2}\sqrt{\frac{r_1+r_2-k}{a}}\text{''}$$

r_1, r_2 are the focal distances of the points P_1, P_2, a is the semi-major axis of the ellipse and n the mean angular velocity about the focus.

The most elegant proof is that due to J. C. Adams,† which will be reproduced here in view of the interesting geometrical results to which it gives rise.

Let μ_1, μ_2 be the eccentric anomalies of P_1, P_2,

$$\therefore\ k^2=a^2(\cos\mu_1-\cos\mu_2)^2+a^2(1-e^2)(\sin\mu_1-\sin\mu_2)^2$$

$$=4a^2\sin^2\tfrac{1}{2}(\mu_1-\mu_2)[1-e^2\cos^2\tfrac{1}{2}(\mu_1+\mu_2)]\quad .\quad .\quad .\quad .\quad (1),$$

$$r_1+r_2=2a-ae\cos\mu_1-ae\cos\mu_2$$
$$=2a[1-e\cos\tfrac{1}{2}(\mu_1+\mu_2)\cos\tfrac{1}{2}(\mu_1-\mu_2)]\quad .\quad .\quad .\quad (2),$$

$$nt=\mu_1-\mu_2-e(\sin\mu_1-\sin\mu_2)$$
$$=(\mu_1-\mu_2)-2e\cos\tfrac{1}{2}(\mu_1+\mu_2)\sin\tfrac{1}{2}(\mu_1-\mu_2)\quad .\quad .\quad .\quad (3).$$

Since a, and therefore n, are given, it follows from (1), (2) and (3) that r_1+r_2, k and t are functions of the two quantities $\mu_1-\mu_2$ and $e\cos\tfrac{1}{2}(\mu_1+\mu_2)$.

---

* "Insigniores orbitæ cometarum proprietates," 1761.
† *British Association Report*, 1877, or Collected Works, p. 410.

$$\text{Let } \mu_1 - \mu_2 = 2\alpha,\ e \cos \tfrac{1}{2}(\mu_1 + \mu_2) = \cos \beta \qquad (4),$$
$$\therefore\ k = 2a \sin \alpha \sin \beta \qquad (5),$$
$$r_1 + r_2 + k = 2a\,[1 - \cos(\beta + \alpha)] \qquad (6),$$
$$r_1 + r_2 - k = 2a\,[1 - \cos(\beta - \alpha)] \qquad (7),$$
$$nt = 2\alpha - 2 \sin \alpha \cos \beta \qquad (8).$$

If now we put $\beta + \alpha = \phi_1$, $\beta - \alpha = \phi_2$, the equations (6) and (7) lead to the required expressions for $\sin \frac{1}{2}\phi_1$, $\sin \frac{1}{2}\phi_2$, whilst (8) gives

$$nt = [\beta + \alpha - \sin(\beta + \alpha)] - [(\beta - \alpha) - \sin(\beta - \alpha)]$$
$$= (\phi_1 - \sin \phi_1) - (\phi_2 - \sin \phi_2)$$

In the figure Q_1, Q_2 are the points on the auxiliary circle which correspond to the points P_1, P_2 on the ellipse, and N_1, N_2 are the feet of the corresponding ordinates. Then $\angle ACQ_1 = \mu_1$, $\angle ACQ_2 = \mu_2$ and $2\alpha = -\angle Q_1CQ_2$

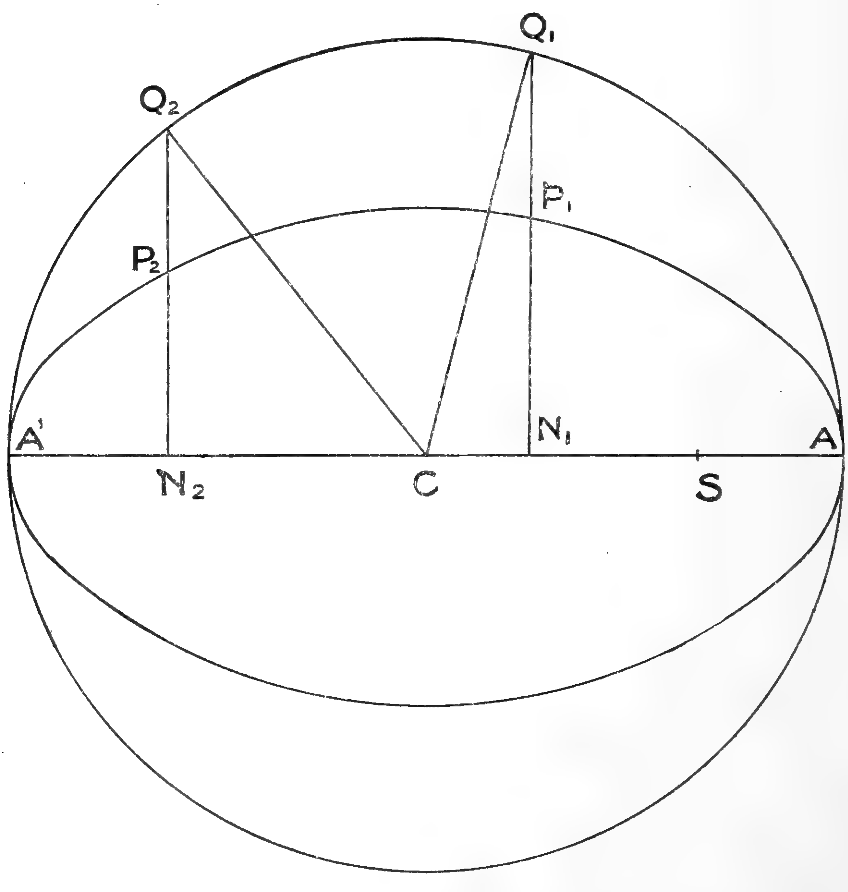


Fig. 1.

Now $ae \cos \frac{1}{2}(\mu_1 + \mu_2)$
$= e.\ CN$, if N is the foot of the ordinate drawn from Q, the middle point of Q_1Q_2. Let P be the corresponding point on the ellipse and r its focal distance. Thus $a \cos \beta = e.\ CN$, by (4), and in order to obtain a geometrical representation for β it is necessary to tranform

the right hand side of this equation so that e disappears. Now in the ellipse $r=a-e.\ CN$ or $e.\ CN=a-r$. Now take a point N' on CA such that $CN'=a-r=e.\ CN$, and let μ' be the eccentric angle of the corresponding point P' on the ellipse. Then clearly $\mu'=\beta$. Hence Adams' proof leads at once to a simple construction for α and β. To construct $\beta+\alpha$ and $\beta-\alpha$ (or ϕ_1 and ϕ_2) let Q' correspond on the auxiliary circle to P' on the ellipse, and take two points Q'_1 and Q'_2 on opposite sides of Q' and such that $\underline{|\,Q'_1CQ'} = \underline{|\,Q'CQ'_2} = \frac{1}{2}\ \underline{|\,Q_1CQ_2}$. Then the angles ACQ'_1 and ACQ'_2 (μ'_1 and μ'_2 say) are equal to ϕ_1 and ϕ_2.

These results suggest that an independent proof of the theorem may be given, based on geometrical considerations. Let P, P'_1, P'_2 be constructed as above. Then with the same notation as before we have $r_1+r_2=2a-ae\cos\mu_1-ae\cos\mu_2$.

$$
\begin{aligned}
&=2a-2\,ae\cos\tfrac{1}{2}(\mu_1+\mu_2)\cos\tfrac{1}{2}(\mu_1-\mu_2)\\
&=2a-2\,CN'\cos\tfrac{1}{2}(\mu'_1-\mu'_2)\\
&=2a-2\,a\cos\tfrac{1}{2}(\mu'_1+\mu'_2)\cos\tfrac{1}{2}(\mu'_1-\mu'_2)\\
&=2a-a\cos\mu'_1-a\cos\mu'_2\\
&=2a-CN'_1-CN'_2\\
&=AN'_1+AN'_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9).
\end{aligned}
$$

$$
\begin{aligned}
\text{Again } k^2&=4a^2\sin^2\tfrac{1}{2}(\mu_1-\mu_2)[1-e^2\cos^2\tfrac{1}{2}(\mu_1+\mu_2)]\\
&=4a^2\sin^2\tfrac{1}{2}(\mu'_1-\mu'_2)\sin^2\tfrac{1}{2}(\mu'_1+\mu'_2)\\
\therefore\ k&=2a\sin\tfrac{1}{2}(\mu'_1-\mu'_2)\sin\tfrac{1}{2}(\mu'_1+\mu'_2)\\
&=a\cos\mu'_2-a\cos\mu'_1\\
&=N'_1N'_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10).
\end{aligned}
$$

Hence, from (9) and (10),

$$\tfrac{1}{2}\sqrt{\frac{r_1+r_2+k}{a}}=\sin\tfrac{1}{2}\mu'_1=\sin\tfrac{1}{2}\phi_1,\quad \tfrac{1}{2}\sqrt{\frac{r_1+r_2-k}{a}}=\sin\tfrac{1}{2}\mu'_2=\sin\tfrac{1}{2}\phi_2.$$

$$
\begin{aligned}
\text{Also } nt&=(\mu_1-\mu_2)-e(\sin\mu_1-\sin\mu_2)\\
&=(\phi_1-\phi_2)-2\,e\sin\tfrac{1}{2}(\mu_1-\mu_2)\cos\tfrac{1}{2}(\mu_1+\mu_2)\\
&=(\phi_1-\phi_2)-2\sin\tfrac{1}{2}(\phi_1-\phi_2)\cos\tfrac{1}{2}(\phi_1+\phi_2)\\
&=(\phi_1-\sin\phi_1)-(\phi_2-\sin\phi_2).
\end{aligned}
$$

Although very different in form from the proof given by Adams the preceding proof is not very different in substance, depending, as it does, on expressing $r+r'$, k and nt in terms of $\mu_1-\mu_2$ and $e\cos\frac{1}{2}(\mu_1+\mu_2)$. It is, however, of some interest as placing the matter on a definitely geometrical basis and for the immediate purpose for which it is here used appears to be superior to the geometrical proofs hitherto given *c.f.* C. Taylor's "Ancient and Modern Geometry of Conics," page 241.

Similar considerations may be applied to obtain corresponding results for the hyperbola, but the results are necessarily more complicated as the representation of points on the curve by means of a single parameter is not of so simple a character as in the ellipse. If the equation of a hyperbola is $\frac{x^2}{a^2}-\frac{y^2}{b^2}=1$ the co-ordinates of any point can be represented by a single parameter, μ, by the relations $x=a \cosh \mu$, $y=b \sinh \mu$. If, in the figure, P is the point (x, y), corresponding to the parameter μ, then $CN=a \cosh \mu$, $PN=b \sinh \mu$, and it is easily shown that the area of the sector CPA is equal to $\frac{1}{2} abu$.

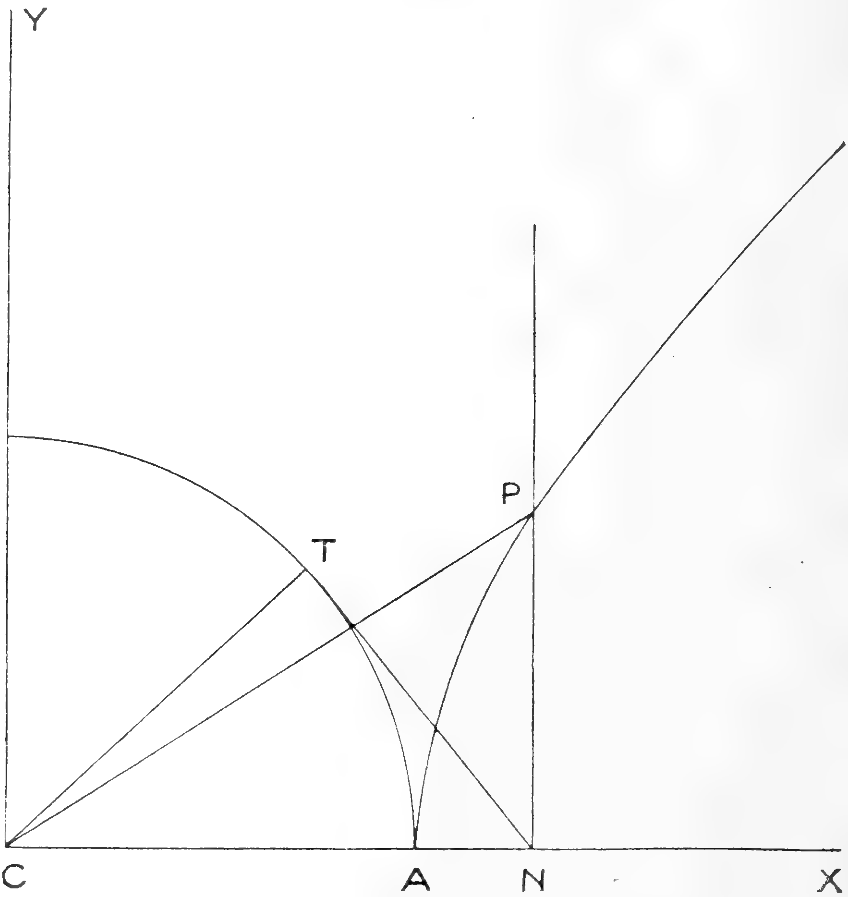


Fig. 2.

Adams'* theorem for the hyperbola may be enunciated as follows :—
"If t is the time of describing any arc P_1P_2 of a hyperbola, and k is the chord of the arc, then $t\sqrt{\frac{\mu}{a^3}} = -\phi_1+\phi_2+\sinh \phi_1 - \sinh \phi_2$,

where $\sinh \frac{1}{2}\phi_1 = \frac{1}{2}\sqrt{\frac{r_1+r_2+k}{a}}$, $\sinh \frac{1}{2}\phi_2 = \frac{1}{2}\sqrt{\frac{r_1+r_2-k}{a}}$."

British Association Report, 1877, or Collected Works, p. 410.

r_1 and r_2 are the focal distances of P_1, P_2, a is the semi-transverse axis, and μ is the acceleration at unit distance.

As before, let μ_1, μ_2 denote the parameters of P_1, P_2.
Then $r_1 + r_2 = ae \cosh \mu_1 + ae \cosh \mu_2 - 2a$

$$= 2\, ae \cosh \tfrac{1}{2}(\mu_1 + \mu_2) \cosh \tfrac{1}{2}(\mu_1 - \mu_2) - 2a.$$

Now let P be the point whose parameter is $\frac{1}{2}(\mu_1 + \mu_2)$ and N the foot of the corresponding ordinate. P will not now be the middle point of P_1P_2.

$$\therefore r_1 + r_2 = 2\, e.\, CN \cosh \tfrac{1}{2}(\mu_1 - \mu_2) - 2a.$$

Let N' be taken on the axis of x so that $CN' = a + r = a + e.\, CN - a = e.\, CN$.

$$\therefore r_1 + r_2 = 2\, CN' \cosh \tfrac{1}{2}(\mu_1 - \mu_2) - 2a.$$

If P'_1, P'_2 are taken on opposite sides of P so that their parameters μ'_1, μ'_2 satisfy the relations $\mu'_1 + \mu'_2 = 2\mu'$, $\mu'_1 - \mu'_2 = \mu_1 - \mu_2$,
we easily find $r_1 + r_2 = AN'_1 + AN'_2$, ... (11)
N'_1, N'_2 being the feet of the ordinates from P'_1, P'_2,
and $k = N'_1 N'_2$ . . . . (12)

$$\therefore \tfrac{1}{2}\sqrt{\frac{r_1 + r_2 + k}{a}} = \tfrac{1}{2}\sqrt{\frac{2AN'_1}{a}} = \tfrac{1}{2}\sqrt{2(\cosh \mu'_1 - 1)} = \sinh \tfrac{1}{2}\mu'_1 = \sinh \tfrac{1}{2}\phi_1,$$

and similarly $\frac{1}{2}\sqrt{\frac{r_1 + r_2 - k}{a}} = \sinh \frac{1}{2}\mu'_2 = \sinh \frac{1}{2}\phi_2$.

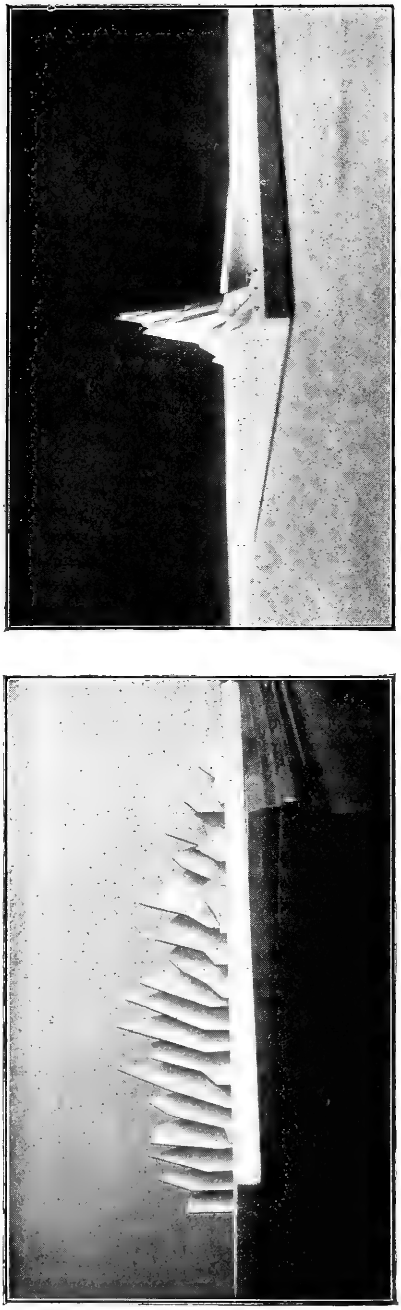
Hence μ'_1, μ'_2 are geometrical representations of ϕ_1, ϕ_2.

Now $t\sqrt{\frac{\mu}{a^3}} = -\mu_1 + \mu_2 + e \sinh \mu_1 - e \sinh \mu_2$*.

$$= -\phi_1 + \phi_2 + \sinh \phi_1 - \sinh \phi_2, \text{ on reduction.}$$

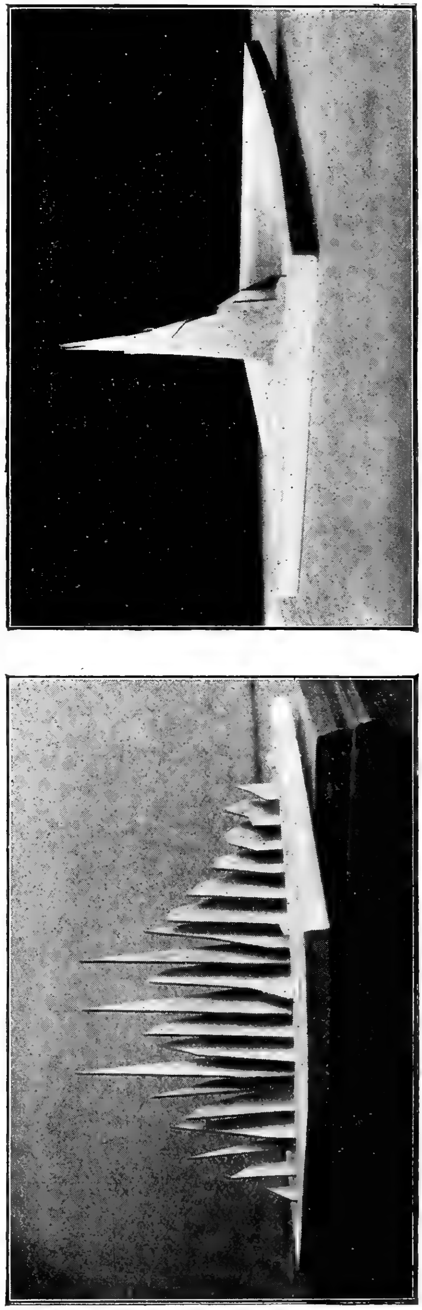
That the analogy between the two cases is complete will be more fully appreciated when it is recollected that in the case of the ellipse, μ, besides denoting the angle ACQ, is also a measure of the sectorial area ACP. In fact the area ACP is equal to $\frac{1}{2}$ *abu*, both in the ellipse and hyperbola. In the case of the ellipse the parameter of P is chosen half way between those of P_1 and P_2 and those of P'_1 P'_2 are so chosen that $\mu'_1 - \mu'_2 = \mu_1 - \mu_2$, $\mu'_1 + \mu'_2 = 2\mu'$.

* Routh's "Dynamics of a Particle," p. 226.



A. B.

Fig. 1. Distribution of Length and Width.
A. Side view. B. End view.



A. B.

Fig. 2. Distribution of Length and Depth.
A. Side view. B. End view.

VOL. 64 : PART II. (END).

MEMOIRS AND PROCEEDINGS

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THE MANCHESTER

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SOCIETY, 1919-20.

CONTENTS.

MANCHESTER:
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Price Seven Shillings.

June 30th, 1921.

II.—Morphogenesis of Brachiopoda.

I.—*Reticularia lineata* (Martin), Carboniferous Limestone.

By W. E. Alkins, M.Sc.

(Communicated by Dr. George Hickling, F.G.S.)

(Read December 2nd, 1919. Received for publication February 17th, 1920.)

Introduction.

In view of the great amount of biometric research that has been carried out during the last few years, it is somewhat surprising that very few investigations along such lines deal with Brachiopoda. The group is represented at the present time by rather less than a hundred and forty species, few of which occur in conditions such as would make them accessible in sufficient numbers for purposes of measurement; but brachiopods, except in the Tertiary rocks, constitute one of the most abundant and most important groups of fossils. Interesting to the zoologist not merely on account of the great age of the group, but also by reason of the extreme variability often exhibited within a single species, and of the prevalence of the phenomenon of heterogenetic homœomorphy, they are of the highest importance to the stratigrapher, since they occur almost world-wide, and frequently in greater abundance than any other group. Hence an enquiry into the variation and growth of a number of species may be of some interest.

Previous Research.

Quantitative studies of variation in certain species of fossil Brachiopoda have been published by Cumings and Mauck (1), by Day (2), and by Mook (3). The first-named authors studied *Platystrophia lynx* from the Upper Ordovician rocks at Vevay, Indiana (Switzerland Co.). The data taken for study were: Ratio of width to length of shell; ratio of depth to breadth of sinus; number of plications on ventral valve; number of plications on dorsal valve; number of plications in sinus; number of plications on fold. In the case of each of these quantities a fairly regular, though slightly asymmetric, distribution curve was obtained; each rose abruptly, and fell off rather less abruptly, showing a certain correlation of the different variants. The correlation between number of plications in the sinus and number of plications on the whole valve, stated in a precise form by Hall, was found to be approximate rather than precise. Extreme forms were small in size, and conversely forms near the modes were large and robust. Finally, there was absolutely no character or combination of characters that could be relied upon to separate any large collection into distinct species, though several such species or varieties had been described; these forms to a limited extent differed in range.

No actual measurements were published. It is perhaps open to criticism that the whole series of shells was not taken from a carefully restricted area.

Day measured a thousand examples of *Reticularia lineata* (Martin) from " one spot in the limestone near Peakshill Farm, Rushup Edge Valley, Castleton." Remarkable variation in the form of individual shells was found, but distribution curves for the ratios $\frac{\text{Length}}{\text{Breadth}}$ and $\frac{\text{Length}}{\text{Depth}}$ gave no indication of the presence of two or more forms. Each of the ratios investigated was found to decrease as the shells increased in size, and the degree of correlation between variation in breadth and variation in depth was found to be equal to about one fifth of the whole variation; apart from this, the variations in breadth and depth occurred quite independently of one another.

Again, no detailed measurements were published. The variation in the $\frac{\text{Length}}{\text{Breadth}}$ and $\frac{\text{Length}}{\text{Depth}}$ ratios as the shells increase in size was only indicated qualitatively, without any attempt at a quantitative treatment. Fortunately Day's series of shells is preserved in the Manchester Museum, and the writer has submitted them to the method of investigation described below.

Mook investigated five mutations of *Spirifer mucronatus*, Conrad, from the Hamilton beds near Thedford, Ontario, and near Alpena and at other localities in Michigan. In the case of each of the mutations studied—mut. *alpenense*, Grabau ms.; mut. *multiplicatus*, Grabau ms.; mut. *profundus*, Grabau ms.; mut. *thedfordense*, Shimer and Grabau; and mut. *attenuatus*, Grabau ms.—distribution curves were plotted for adult and neanic shell indices, *i.e.*, $\frac{\text{Breadth}}{\text{Length}}$ ratios. From the results it was concluded that *alpenense* is ancestral to *profundus* and *thedfordense*, whilst *attenuatus* and *multiplicatus* are derived from some common form similar to but somewhat more primitive than *multiplicatus*.

While the conclusions drawn by Mook are perhaps valid, the more purely statistical portion of the work calls for certain criticisms. Only 74 specimens of the form *attenuatus* were measured; the curves for *multiplicatus* are based on the still smaller number of 29 specimens. Yet in each case the percentage of shells within any given range of index is returned to the nearest one-tenth of one per cent., *i.e.*, in the case of *multiplicatus* the tacit assumption is made that the relations found for 29 specimens would hold exactly for one thousand. A much more serious point is that we are not told how the neanic measurements were obtained. Mook appears to have regarded all his examples as adult, however small they may have been; hence we find the neanic measurements of various individuals exactly the same as the adult measurements of other individuals; the latter therefore would appear to be immature (*e.g.*, neanic specimen no. 53=adult no. 38, etc.). Again, the neanic width is always given as equal to the adult width; thus, it is assumed that after the neanic stage has been passed the shell grows longer but not wider, the length of the hinge-line remaining unaltered. While the growth-lines are certainly much more crowded towards the ends of the hinge-line than they are near the anterior margin of the shell, increase in length is always accompanied by increase in width, *i.e.*, although $\frac{dw}{dl}$ diminishes very considerably as the shell increases in size, yet it is always appreciable. For these reasons the neanic curves of Mook are of very little value.

The measurements of every specimen are published, and these the writer proposes to use in order to obtain "growth-curves," so far as the data will allow.

In a recent note (4) the writer showed that in the case of the recent freshwater bivalve *Unio pictorum*, Linné, the ontogenetic curve of growth for the ratio antero-posterior length/dorso-ventral length, as determined by measurements from the growth-lines of individual shells, was in complete agreement with the phylogenetic curve obtained by measuring a large series of shells in all stages of growth and determining the mean value of the major axis which corresponded with each given dorso-ventral length. It is proposed to investigate the growth of various Brachiopoda by the method employed for the *Unio* above mentioned.

The Present Research.

In the present paper the writer proposes to give the results of a study of the series of *Reticularia lineata* (Martin) measured by Day. The specimens preserved in the Manchester Museum number nine hundred and forty-five (Day measured one thousand). Day did not accurately define the position of the three axes, Length, Breadth, and Depth, measured by him, and therefore no attempt had been made to discover whether the results of the measurement of the same series of shells by different observers were in accordance. Indeed, the values of the two ratios $\frac{\text{Width}}{\text{Length}}$ and $\frac{\text{Depth}}{\text{Length}}$ have not been determined, since the present investigation was undertaken with the object of studying the growth rather than the variation of the species.

The history of the species was sketched by Day, who also dealt at length with variations in certain characters less susceptible of measurement—variation in size, and lateral twisting of the ventral beak, ornament, etc.—as well as with variations in form. It is therefore unnecessary to treat of these features here.

Measurement. The three axes Length, Width, and Depth, were measured by means of an optician's sliding gauge, the determination being in every case correct to the nearest millimetre. The position of the axes may be defined as follows:—

Length. From the brachial umbo to the anterior margin, along the plane of symmetry of the shell. By measuring from the brachial umbo, irregularities due to variation in the relative size of the umbones—which are much greater in the case of the pedicle (ventral) umbo—are considerably diminished.

Width. The greatest width, perpendicular to the length axis and to the plane of symmetry.

Depth. The greatest thickness of the shell, perpendicular to the axes of width and length.

All shells of the same length were now got together, the whole series being thus divided up into a number of smaller series, each comprising shells which had attained the same length. In each of these small series width and depth distribution curves were plotted, and these were utilised to construct skeleton solid figures, in which the horizontal axes represent (1) length and (2) width or depth, the vertical axis representing the number of specimens. The data on which these figures are based are given in Tables I and II, while photographs of the skeleton figures are shown in *Figs.* 1 and 2; the method adopted will probably be evident from Tables I and II (in constructing the solid figures outlying specimens have been disregarded).

TABLE I.

Comparison of Width with Length.

Length	Width	No.	Mean Width
3	4	1	4
4	4 5	6 2	4·25
5	5 6 7	12 11 1	5·54
6	6 7 8	9 20 3	6·81
7	7 8 9 10	7 22 8 1	8·08
8	8 9 10 11	5 22 20 3	9·42
9	8 9 10 11 12 13	1 2 16 22 6 4	10·82
10	10 11 12 13 14	2 18 30 11 3	11·92
11	11 12 13 14 15 16 17	3 7 20 20 9 – 1	13·48
12	13 14 15 16 17	7 17 29 11 3	14·79
13	14 15 16 17 18 19 20	6 16 27 19 3 2 1	16·09

Length	Width	No.	Mean Width
14	15 16 17 18 19 20	5 14 23 13 13 4	17·38
15	15 16 17 18 19 20 21 22	1 5 11 15 12 14 9 3	18·79
16	17 18 19 20 21 22 23 24	3 6 18 15 11 8 3 1	20·02
17	19 20 21 22 23 24 25	4 10 22 17 13 6 1	21·64
18	18 19 20 21 22 23 24 25 26 27 28	2 2 4 8 4 11 14 4 5 1 1	22·93

Length	Width	No.	Mean Width
19	21 22 23 24 25 26 27 28	1 1 3 6 15 6 5 2	25·08
20	22 23 24 25 26 27 28 29 30 31	2 7 4 5 8 3 6 6 1 1	26·02
21	25 26 27 28 29 30 31 32 33	6 10 7 5 3 1 1 – 1	27·06
22	25 26 27 28 29 30 31	1 3 2 6 5 1 1	28·47
23	29 30 31 32	2 1 – 1	30·0
24	33	1	33

TABLE II.

Comparison of Depth with Length.

Length	Depth	No.	Mean Depth
3	2	1	2
4	2 3	1 7	2·88
5	3 4	15 9	3·38
6	4 5	27 5	4·16
7	4 5 6	7 29 2	4·87
8	5 6 7	25 21 4	5·58
9	6 7	33 18	6·35
10	6 7 8	10 49 5	6·92
11	6 7 8 9 10	1 22 31 5 1	7·72
12	7 8 9 10	2 34 28 3	8·48
13	8 9 10 11	7 47 18 2	9·20
14	8 9 10 11 12	1 9 32 28 2	10·29
15	10 11 12 13	7 48 11 4	11·17
16	10 11 12 13	5 16 33 11	11·77
17	10 11 12 13 14 15	1 2 27 26 14 3	12·81
18	12 13 14 15 16 17 18	3 22 19 9 2 – 1	13·80
19	13 14 15 16 17 18	3 16 15 4 – 1	14·62
20	14 15 16 17 18 19 20	6 12 13 9 2 – 1	15·84
21	15 16 17 18	6 7 13 8	16·68
22	16 17 18	3 6 10	17·37
23	18 19 20	1 2 1	19·0
24	19	1	19

The solid figures show that *Reticularia lineata* presents a very good example of a truly homogeneous species: the variation shown is perfectly continuous throughout, and there is not the slightest evidence of any tendency towards a differentiation into two or more groups. Such solid figures may be taken as typical of "good," simple, homogeneous species.

Ontogeny. We may now safely proceed with a mathematical investigation into the ontogeny of the shell.

From the data necessary for the construction of the length-width and length-depth distribution figures the mean value of the width and depth respectively corresponding to each length was calculated. These mean figures are included in Tables I and II. They represent the average width and depth of shells which have attained any given length, and have been utilised for the construction of *Figs.* 3 and 4. In *Fig.* 3 the mean width, and in *Fig.* 4 the mean depth, is plotted against the length. The same figures show also the range in width and in depth which was found amongst shells of each length—and again, the actual values may be found by reference to Tables I and II.

It should be observed that this method is only applicable in the case of species which show no tendency towards division into two or more groups: any such tendency is at once brought out by the solid distribution figures, and when evidence of a differentiation of this kind is found the ontogeny of the species cannot be directly studied by the method outlined above.

The remarkable smoothness of each of the ontogeny curves provides a very striking justification for the method by which they have been obtained. The discrepancy between the actual mean width or depth values and the corresponding points on the mean curves upon which they appear to lie is throughout very small. The two curves may now be considered somewhat more closely.

At the outset it may be remarked that the curves confirm the statement of Day that the ratios $\frac{\text{Length}}{\text{Width}}$ and $\frac{\text{Length}}{\text{Depth}}$ decrease throughout the life of the individual. But they show very definitely that the relationship which exists between Width and Length is by no means similar to that which is found between Depth and Length—a feature that the purely qualitative method used by Day could not be expected to bring out.

Fig. 3 shows that the width and length are related throughout life by a linear function, which may be expressed:—

$$w = 1{\cdot}35\ (l - 1{\cdot}0),$$

where l=length in mm., w=width in mm.

Two points of interest arise in this connection. Obviously, the line corresponding with this function does not pass through the origin: the width is directly proportional to a quantity which is roughly one millimetre less than the length as measured, *i.e.*, from the brachial umbo to the fold. Consideration of the form of the shell affords a fairly simple explanation of this. The brachial umbo projects to a slight extent behind the hinge-line; the extremities of the width axis lie in the plane of the hinge-line and the anterior margin, not in that of the brachial umbo and the anterior margin. Thus it appears highly probable that the width is directly proportional to the length from the hinge-line to the anterior margin. This suggestion is supported by the fact that 1 mm. is quite a fair average value for the difference between the lengths as measured from the hinge-line and from the brachial umbo respectively. No such correction for the length is necessary in the case of the relationship between depth and length.

The average values of the ratio $\frac{\text{Length}}{\text{Width}}$ are less than those given by Day (*loc. cit., Fig.* 4): it therefore appears likely that Day took his length from the pedicle umbo to the anterior margin —which would at once account for the fact that the rate of decrease of the ratio during the growth of the shell does not agree very closely with the rate which may (approximately) be deduced

$$\text{Since} \quad w = 1{\cdot}35(l-1), \quad \text{we have:} \quad \frac{dw}{dl} = 1{\cdot}35\,;$$

i.e., the width increases at a constant rate, which is equal to 1·35 times the rate of increase of the length.

$$\text{Also} \quad \frac{w}{l} = 1{\cdot}35\left(1-\frac{1}{l}\right) = 1{\cdot}35-\frac{1{\cdot}35}{l}$$

$$\therefore \quad \frac{d\left(\frac{w}{l}\right)}{dl} = \frac{1{\cdot}35}{l^2}\,;$$

i.e., as the length increases, the ratio $\frac{\text{Width}}{\text{Length}}$ increases rapidly at first and then more and more slowly, the increase being very small when the length is great.

The relationship between depth and length is rather less simple (*Fig.* 4). Over the whole range covered by the specimens studied, the two dimensions are very well expressed by the relation: $D = 0{\cdot}6643l + 0{\cdot}0011l^2 + 0{\cdot}000247l^3$; where D=depth, l=length, in millimetres. The agreement between the experimental values and the curve given by this equation is remarkably good (little weight is to be attached to the last two or three points found, on account of the relatively small number of such large specimens in the series).

$$\text{Since} \quad D = 0{\cdot}6643l + 0{\cdot}0011l^2 + 0{\cdot}000247l^3,$$

$$\therefore \quad \frac{dD}{dl} = 0{\cdot}6643 + 0{\cdot}0022l + 0{\cdot}000741l^2\,;$$

i.e., the rate of increase of depth increases more and more rapidly as the length increases.

$$\text{Further,} \quad \frac{D}{l} = 0{\cdot}6643 + 0{\cdot}0011l + 0{\cdot}000247l^2\,;$$

$$\therefore \quad \frac{d\left(\frac{D}{l}\right)}{dl} = 0{\cdot}0011 + 0{\cdot}000494l\,;$$

i.e., the rate of increase of the ratio $\frac{\text{Depth}}{\text{Length}}$ increases at a constant rate as the length increases.

It is therefore evident that the relation between depth and length throughout growth is very different from that between width and length.

Summary and Conclusion.

It has been shown that:—

1. Length-Width and Length-Depth solid distribution figures strongly confirm the view that *Reticularia lineata* (Martin) from brachiopod-beds near Castleton, Derbyshire, is a perfectly homogeneous species.

2. Throughout life the length (l) from the brachial umbo to the anterior margin and the width (w) are connected by the relation:— $w = c_1(l - c_2)$, where c_1 and c_2 are constants.

It is suggested that c_2 is equal to the mean difference between the length from the brachial umbo and that from the hinge-line, to the anterior margin.

3 Simultaneously the depth (D) and length are related by the expression:—

$$D = al + bl^2 + cl^3, \text{ where } a, b, c \text{ are constants.}$$

Finally, the writer would like to express his cordial thanks to Dr. G. Hickling, F.G.S., and to Mr. J. Wilfrid Jackson, F.G.S., for the kind interest they have taken throughout in the work; to Mr. J. Harwood, B.Sc., to whom the author is indebted for the photographs of the solid figures, and for considerable assistance in checking many of the calculations incidental to the analysis of the results; and to Professor Sydney Chapman, M.A., D.Sc., F.R.S., for the interest he has shown in the mathematical side of the work.

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The University, Manchester,
October 30th, 1919.

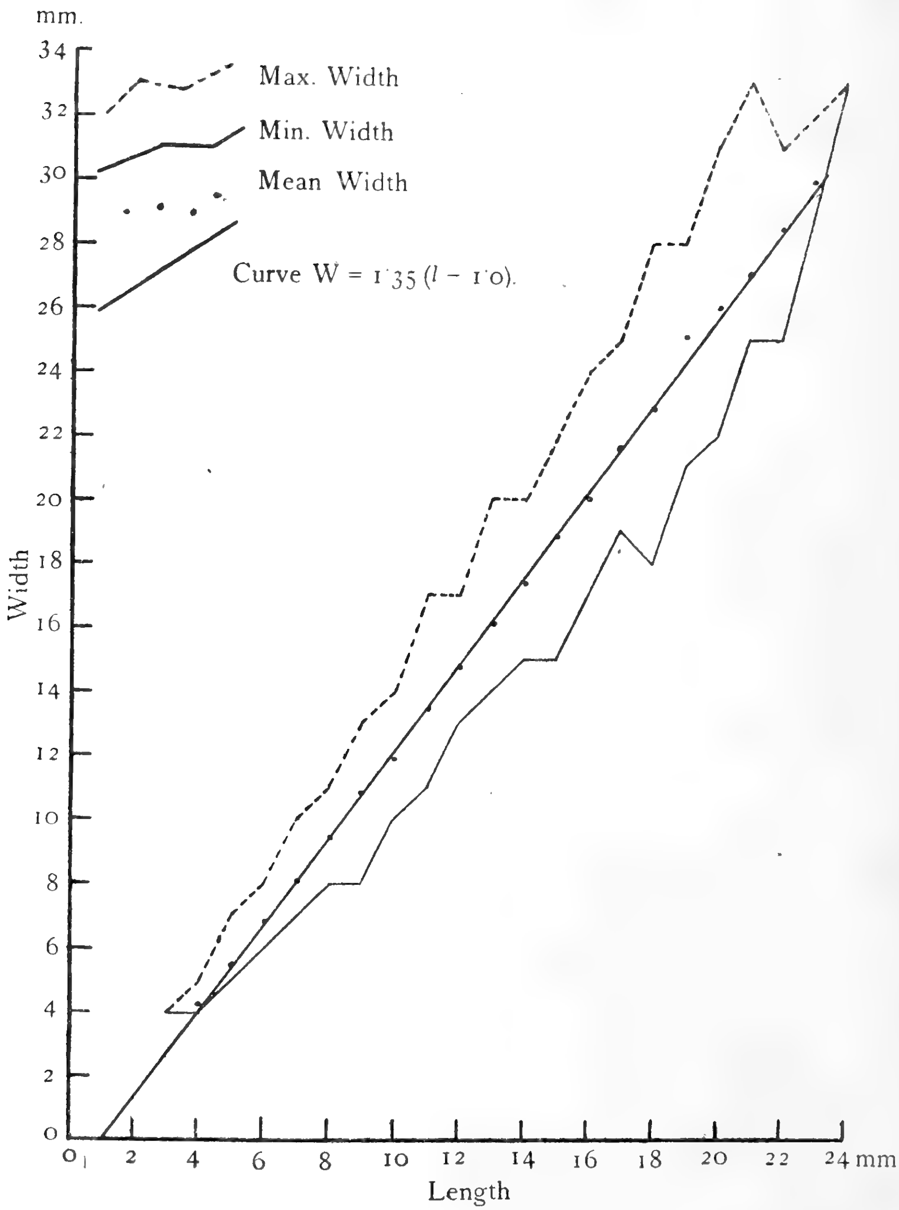


Fig. 3. **Relationship between Length and Width.**

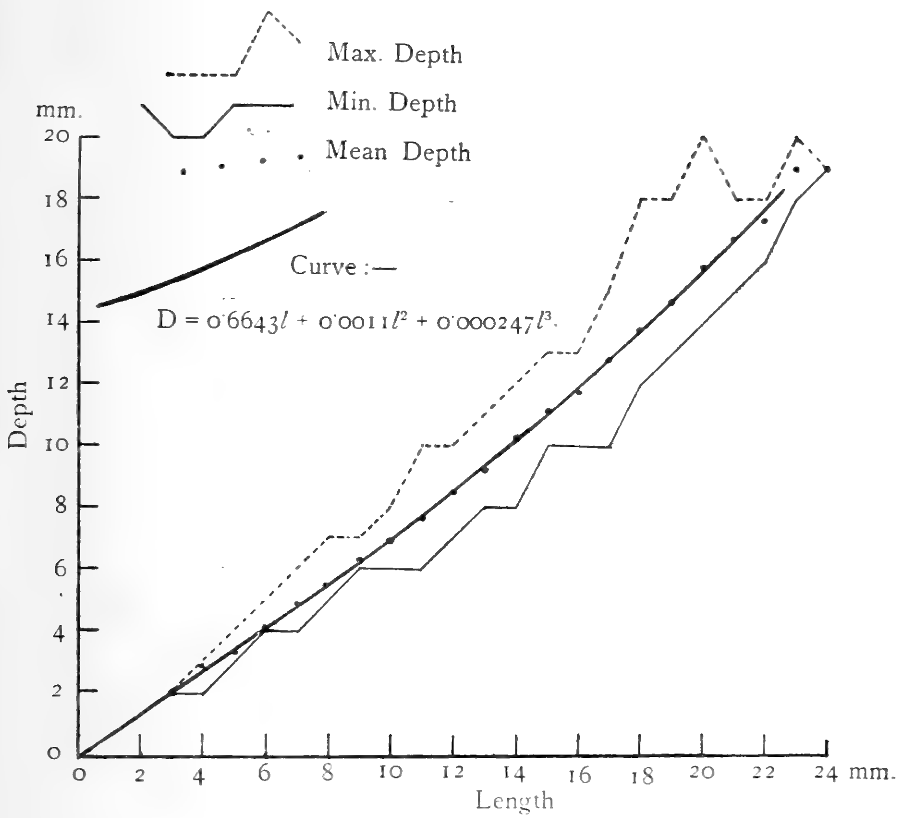


Fig. 4. **Relationship between Length and Depth.**

Manchester Memoirs, Vol. lxiv. (1920), *No.* **3**

III.—Latent polarities of atoms and mechanism of reaction, with special reference to carbonyl compounds.

By Professor ARTHUR LAPWORTH, D.Sc., F.R.S.

(Read March 16th, 1920. Received for publication March 29th, 1920.)

THE conception introduced by J. J. Thomson that the conventional valency "bond" between two atoms corresponds with the field between two opposite electrical charges situated on the atoms has been utilised by Ramsay, Fry and many other chemists to aid in accounting for phenomena of the most diverse character, such as the laws of substitution in the benzene series and the decompositions of citric acid and of aceto-acetic acid (Fry, *Zeitsch. physikal. Chemie*, 1911, **76**, 385, 398, 591; *J. Amer. Chem. Soc.*, 1908, **30**, 34; 1912, **34**, 664; 1914, **36**, 284, etc.; 1915, **37**, 855, etc.; 1916, **38**, 1323, etc. Hancke and Koessler, *J. Amer. Chem. Soc.*, 1918, **40**, 1726. Compare also Vorländer, *Ber. d. Deutsch. Chem. Gesellsch.*, 1919, **52** [B], 263.)

The writer has for a number of years used for his own guidance, and to a certain extent in teaching, a system of representing the activities of carbon compounds which involves the labelling of the atoms in the molecule with + and − signs, and with results which do not at first sight differ greatly from the figurations developed by Fry and others. In one very important particular he is in agreement with Noyes, Fry and others of this school in holding that the terms "positive" and "negative" have in the past been widely misapplied to many atoms and groups; for example, it has been customary to term $-NH_2$ a "positive" group, and acetyl $CH_3{\cdot}CO-$ a "negative" group, while in point of fact when these groups are united, forming acetamide, $CH_3{\cdot}CO-NH_2$, and set in competition with one another for the components of the water molecule, it is the acetyl group which attracts the truly negative hydroxyl and the $-NH_2$ group which attracts the positive hydrogen,

$$\left.\begin{array}{l} \overset{+}{H} — \overset{-}{OH} \\ \quad\text{and} \\ \underset{-}{NH_2}—\underset{+}{CO.CH_3} \end{array}\right\} \rightarrow \left\{\begin{array}{ccc} \overset{+}{H} & & \overset{-}{OH} \\ | & \text{and} & | \\ \underset{-}{NH_2} & & \underset{+}{CO.CH_3} \end{array}\right.$$

October 22nd, 1920.

and every acceptable test of this kind leads to the same inversion of the customary application of the terms "positive" and "negative" to these two groups. The writer would propose the term "basylous" for such a group as $-NH_2$ which tends to lower the acidity of a molecule of which it forms but a part, and the term "acylous" for a group such as $CH_3{\cdot}CO-$ which has the opposite effect. Thus $-NH_2$, $-NHAlk.$, etc., are basylous, but almost invariably exhibit positive polarity when attached to carbon; $-H$ is basylous and usually positive; $-CO-$, $-SO_3H$ and $-NO_2$ are strongly acylous but usually positive; while $-OH$, $-OAlk.$, etc., are acylous and negative. Halogens are acylous and normally negative, but are positive when contrasted with $-OH$ or $-NH_2$.

$$\left.\begin{array}{c} \overset{+}{\mathrm{Cl}} - \overset{-}{\mathrm{OH}} \\ \text{and} \\ \underset{-}{\mathrm{Cl}} - \underset{+}{\mathrm{H}} \end{array}\right\} \longleftrightarrow \left\{\begin{array}{ccc} \mathrm{Cl} & & \mathrm{OH} \\ | & \text{and} & | \\ \mathrm{Cl} & & \mathrm{H} \end{array}\right.$$

$$\left.\begin{array}{c} \overset{+}{\mathrm{Cl}} - \overset{-}{\mathrm{NH_2}} \\ \text{and} \\ \underset{-}{\mathrm{HO}} - \underset{+}{\mathrm{H}} \end{array}\right\} \longleftrightarrow \left\{\begin{array}{ccc} \mathrm{Cl} & & \mathrm{NH_2} \\ | & \text{and} & | \\ \mathrm{HO} & & \mathrm{H} \end{array}\right.$$

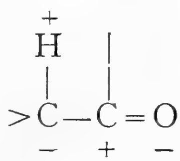
Compounds containing positive acylous groups yield acids by union with negative hydroxyl, and those with negative basylous groups yield bases with positive hydrogen (or $\overset{+}{H} + H_2O$). In the following pages the terms positive and negative are restricted to the application above indicated.

The writer originally fell into the habit of labelling the atoms in reactive molecules with + and − signs as the result of his applications of the ionic theory to the reactions of carbon compounds, and especially to those of ketones and allied carbonyl compounds. Thus it was evident that the addition of electrolytes to the carbonyl group invariably proceeded as if the carbon atom were more positive than the oxygen atom, and invariably selected the negative ion; for example,

$$\left.\begin{array}{c} >\overset{+}{\mathrm{C}} = \overset{-}{\mathrm{O}} \\ \text{and} \\ \underset{-}{\mathrm{CN}} - \underset{+}{\mathrm{H}} \end{array}\right\} \rightarrow \begin{array}{ccc} >\mathrm{C} & - & \mathrm{O} \\ | & & | \\ \mathrm{CN} & & \mathrm{H} \end{array}$$

conveniently indicated the course of the well-known cyanohydrin formation. It must be emphasised, however, that in attaching the − and + signs to the oxygen and carbon atoms no hypothesis is invoked, nor is it necessary or even desirable to assume that electrical charges are developed on these two atoms (except perhaps at the actual instant of chemical change). The signs are applied, in the first instance, merely as expressing the relative polar characters which the two atoms seem to display at the instant of the chemical change in question. In this respect the writer's views differ from those of Fry and others, and agree with those of Robinson.

The aldol reaction, in which compounds containing the groups $>CH-CO-$, $>CH-NO_2$, $>CH-CN$, etc., can replace the hydrogen cyanide in the addition process pictured in the paragraph immediately preceding, at once suggests that the hydrogen atom in these groupings has an enhanced positive polar character relatively to the carbon atom on which it is situated, and accordingly the writer expresses this by attaching a + and a − sign to these two atoms respectively. Combining this with the expression already developed for the carbonyl group, there is obtained the scheme :



It may now be noted that this fusion suggests a property of the whole system which was not taken into consideration in deducing the signs for the two parts, and which, if absent, would render it impossible to justify the use of the scheme as a whole; this property concerns the two carbon atoms, which are here necessarily shown as having opposite polarities with respect to one another, and in the same sense as with the hydrogen atom and the carbon atom on the left. Fortunately there is plenty of evidence in favour of the existence of latent polarisation in a pair of carbon atoms situated as in the above scheme; thus hydrolysis of such a complex usually if not invariably takes place as follows :—

$$\underset{-}{>CH} - \underset{+}{\overset{|}{C}} = \underset{-}{O} + \overset{+}{H} - \overset{-}{O}H \rightarrow >\underset{-}{C}H\overset{+}{H} + H\overset{-}{O}\cdot\underset{+}{\overset{|}{C}} = \underset{-}{O}.$$

Significant too are the properties of $\alpha\beta$-unsaturated ketones;

etc., where it is clear that the doubly linked carbon atoms and the carbonyl group are to be labelled as in the scheme

$$\left.\begin{array}{c} -\overset{|}{\underset{+}{C}}=\overset{|}{\underset{-}{C}}-\overset{|}{\underset{+}{C}}=\underset{-}{O} \\ \text{and} \\ \underset{-}{CN}-\underset{+}{H} \end{array}\right\} \rightarrow \begin{array}{c} -\overset{|}{C}-\overset{|}{C}-\overset{|}{C}=O \\ \begin{array}{cc} | & | \\ | & | \\ CN & H \end{array} \end{array}$$

As a considerable step in advance of this may be quoted the fact, foreseen and established by the writer eighteen years ago, that the hydrogen atoms of the γ-position in ethyl crotonate have properties precisely corresponding with those of the hydrogen atoms in the α-position in saturated carbonyl compounds (*Trans. Chem. Soc.*, 1901, **79**, 1273), so that the formulation $\underset{+}{H}-\underset{-}{CH_2}\cdot CH:CH\cdot COOEt$ must be adopted to express this. Combining this with the scheme developed immediately above there results the extended form:

$$\begin{array}{ccccccccccc} & & & & & & & & \text{O Et} & & \\ H & - & CH_2 & - & CH & = & CH & - & \dot{C} & = & O, \\ + & & - & & + & & - & & + & & - \end{array}$$

and although, at present, it is difficult to find direct justification for the implied relative polarities of the two bracketed carbon atoms, the weight of evidence in favour of the conclusion that the carbonyl group tends to develop alternate $-$ and $+$ latent polarities in a chain of atoms is so considerable that it seems reasonable to proceed with the further development of the principle in the confident belief that this solitary hiatus will disappear in due course.

The polar properties of crotonic aldehyde are no doubt to be represented by a precisely similar scheme, and the more recent work of Raper and of Mrs. MacLean on the synthetic production, from aldol and crotonic aldehyde, of compounds containing straight chains of eight carbon atoms furnishes evidence of this, and suggests that the biochemical synthesis of fatty acids is regulated by the principle of alternating latent polarities.

$$2\,\overset{-}{CH_3}\cdot\overset{+}{CH}:\overset{-}{CH}\cdot\overset{+}{CH}\overset{-}{O} \rightarrow \overset{-}{CH_3}\cdot\overset{+}{CH}:\overset{-}{CH}\cdot\underset{\underset{-\ +}{OH}}{\overset{+}{CH}}\cdot\overset{-}{CH_2}\cdot\overset{+}{CH}:\overset{-}{CH}\cdot\overset{+}{CH}:\overset{-}{O}$$

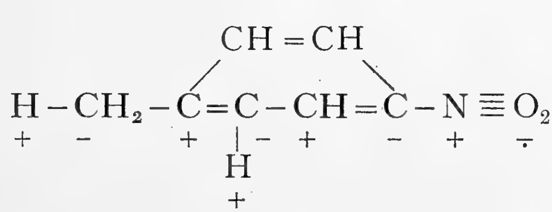
It must now be evident from the cases already dealt with, that the whole order of alternating latent polarities is determined by the oxygen atom or atoms, for the rest of the molecule consists of carbon and hydrogen atoms only. The influence of $-NO_2$, $-SO_2-$, and $-CN$ when in attachment to carbon differs, however, only in degree from that of carbonyl; hence it would appear that with the first two the effect of the group on the rest of the molecule is again determined by the oxygen atoms and in the last by the nitrogen atom. The analogy between the four different groups may therefore be indicated as follows, where in each case the "key-atom" is suggested by addition of a "dot" to the sign used for its latent polarity.

$$\begin{array}{ccccccc} C & - & C & - & C & = & O \\ + & & - & & + & & \underset{\cdot}{-} \end{array} \qquad \begin{array}{ccccccc} C & - & C & - & N & \equiv & O_2 \\ + & & - & & + & & \underset{\cdot}{-} \end{array}$$

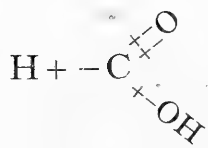
$$\begin{array}{ccccccc} C & - & C & - & S & \equiv & O_2 \\ + & & - & & + & & \underset{\cdot}{-} \end{array} \qquad \begin{array}{ccccccc} C & - & C & - & C & \equiv & N \\ + & & - & & + & & \underset{\cdot}{-} \end{array}$$

The writer has long held that certain atoms, and especially divalent oxygen and tervalent (negative) nitrogen, tend to produce such an alternation of latent polarities within the molecules in which they occur. These two atoms are as a rule much more effective than the halogens and, where they are in competition, the influence of the oxygen usually appears greater than that of the nitrogen. A perceptible influence of the opposite kind appears to be exercised by hydrogen. Carbon itself (in part no doubt because it is the standard of reference) appears nearly indifferent, as also does quinquevalent nitrogen.

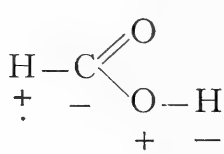
The extension of the influence of the directing, or "key-atom," over a long range seems to require for its fullest display the presence of double bonds, and usually in conjugated positions; consequently the principle must find ample scope in the aromatic series where conjugation is the rule. The ready substitution of the γ-hydrogen atoms in ethyl crotonate was shown by the writer in 1901 to provide an exact parallel with the behaviour of the hydrogen atoms in the methyl group of *o*- and *p*-nitrotoluene, and both were shown to be cases of "meta-substitution." The scheme



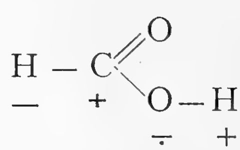
illustrates the far-reaching influence of the polarising "key-atoms" on the properties of the hydrogen atoms both in the *meta* position and in the methyl group of *p*-nitrotoluene and the relation between this arrangement and the less extended one for ethyl crotonate strengthens the case for concluding that the influence of any "key-atom" on a chain of other atoms is to influence their latent polarities in the sense which the writer attaches to the alternating + and − signs of the preceding schemes.

It is this kind of influence which the writer considers to have the greatest importance in the development of the principle of latent polarities and which should always be expressed in employing it. The expression , adopted by Fry and other authors of this school, for formic acid (compare *J. Amer. Chem. Soc.*, 1914, **36**, 1035) is used by them to express several, probably unrelated, properties of the acid simultaneously. It is doubtless quite consistent with Thompson's theory of a bond; but this theory provides no explanation of the principle which the present writer desires to emphasise and with which principle such formulæ are inconsistent.

Formulæ A and B indicate the application of the principle of alternating latent polar influences as expressing the influence of the methin hydrogen atom and the hydroxylic oxygen respectively in modifying the latent polarities of the other atoms in the chain of four:—

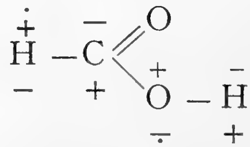


(A)



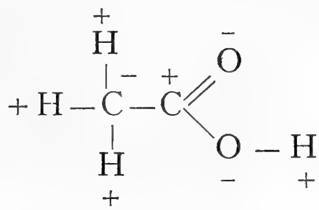
(B)

There are possibly two isodynamic phases of the molecule or, much less probably, the effects are superimposed, in which case an expression



would make clear the two opposing, doubtless very unequal, influences.

The arrangement of the molecule of formic acid may be said to be *heterogeneous* from the point of view just elaborated; acetic acid on the other hand is wholly *homogeneous*, the signification remaining the same no matter which of the oxygen or hydrogen atoms is imagined to act as "key-atom,"



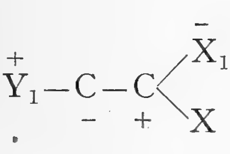
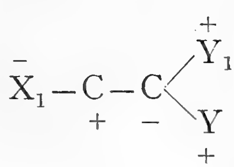
and the same is true of aceto-acetic acid (Hancke and Koessler, *loc. cit.*).

In order to emphasise that aspect of the question of polarities to which he attaches special importance the writer would suggest terming it the "principle of induced alternate polarities."

It is evident that the rule of Markownikoff is at once the most natural and elementary outcome of the principle in question, as the addition processes

$$\overset{-}{X_1}\cdot\overset{+}{Y_1} + \underset{-}{C}=\underset{+}{C}-\underset{-}{X} \qquad \text{and } \overset{-}{X_1}\cdot\overset{+}{Y_1} + \underset{+}{C}=\underset{-}{C}-\underset{+}{Y}$$

must give rise to

 and 

or, in words, to the accumulation of atoms or groups of like polar character on the same carbon atom.

It would seem that, in general, the reversible reactions are those which lead to the most homogeneous arrangements, as in the aldol, acetoacetic ester and Raper-MacLean syntheses; heterogeneous arrangements appear usually to arise as the result of depolarisation effects analogous to oxidation or reduction: but this issue as well as that of variable valency and consideration of amphoteric groups like $-CN$ must for the present be deferred.

The influence of one atom in a molecule in modifying the polar character of another is well illustrated by the properties conferred on halogen atoms by oxygen atoms variously situated with regard to them. For example, with the grouping

$$\underset{+}{\mathrm{Cl}} - \underset{-}{\mathrm{C}} - \underset{+}{\mathrm{C}} = \underset{\underset{\cdot}{-}}{\mathrm{O}}$$

there is abundant evidence that the chlorine atom has an enhanced tendency to act as a positive, and a diminished tendency to react as a negative, component; it is, for example, frequently difficult to replace it except by positive hydrogen. Thus, the α-chloroderivatives of camphor are not converted by alkalies or silver hydroxide into hydroxycamphor, and in the case of $\alpha\alpha'$-*di*chloro-camphor alcoholic sodium hydroxide actually causes replacement of one chlorine atom by hydrogen, the product being *mono*chlorocamphor. Again, the α-halogen derivatives of ketones, and especially of 1:3-diketones and 1:3-ketonic esters, react excessively readily with hydrogen iodide in dilute solution (Kurt Meyer's test for *enol* forms), and even with hydrogen bromide, free halogen being liberated

$$\underset{+}{\mathrm{H}} - \boxed{\underset{-}{\mathrm{Br}} \quad + \quad \underset{+}{\mathrm{Br}}} - \underset{-}{\ddot{\mathrm{C}}} - \underset{+}{\dot{\mathrm{C}}} = \underset{\underset{\cdot}{-}}{\mathrm{O}}$$

On the other hand the properties of halogen in the β-position in carbonyl compounds offers a striking contrast with this. The $\alpha\beta$-*di*halogen derivatives, when halogen hydride is withdrawn, lose the halogen atom from the β-position, which fact indicates that the latent polarity of the β-halogen in these compounds is negative. Combining this result with that above deduced for the α-halogen derivatives, it is seen that the scheme

$$\begin{array}{ccccccc}
 & & & \overset{+}{\mathrm{Br}} & & & \\
 & | & & | & & | & \\
- & \mathrm{C} & - & \mathrm{C} & - & \mathrm{C} & = \mathrm{O} \\
 & |\,+ & & |\,- & & + & \quad \underset{\cdot}{-} \\
 & \underset{-}{\mathrm{Br}} & & \underset{+}{\mathrm{H}} & & &
\end{array}$$

expresses all the data drawn attention to, and is one in which the oxygen atom functionates as "key-atom." It is perhaps doubtful whether the influence of the oxygen atom extends so far as the β-halogen atom and whether the lability of the latter atom is not consequent on the induced polarity of the α-hydrogen atom; such a question awaits further experimental evidence. Space does not permit of discussion of possible phases of, or effects in, the above arrangement of atoms when the halogen atoms in their turn exercise functions as "key-atoms."

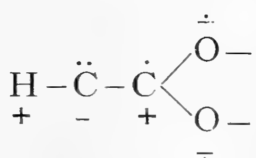
It may at this point be emphasised that while double (and treble ?) bonds are highly effective when suitably disposed for carrying on the influence of a "key-atom" over a long chain, similar influences may often be traced, though as a rule less clearly, in the entire absence of double bonds. Thus the decided lability and latent "positiveness" of the hydrogen atom noticed in the group

$$\begin{array}{ccccccc} \mathrm{H} & - & \ddot{\mathrm{C}} & - & \dot{\mathrm{C}} & = & \mathrm{O}. \\ + & & - & & + & & \underset{\cdot}{-} \end{array}$$

is also discernible in the group

$$\begin{array}{cccccccc} \mathrm{H} & - & \ddot{\mathrm{C}} & - & \ddot{\mathrm{C}} & - & \mathrm{O} & - \\ + & & - & & + & & \underset{\cdot}{-} & \end{array}$$

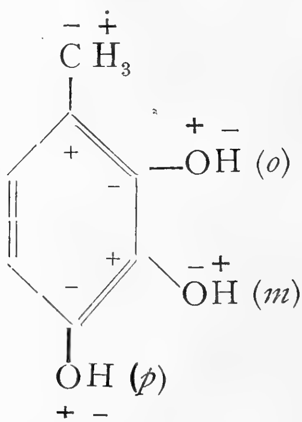
for ethyl ether readily yields $\alpha\beta$-*di*chloro derivatives, and ethyl alcohol condenses with certain aldehydes in virtue of labile hydrogen in its methyl group. More evident is the combined effect of two singly bound oxygen atoms homogeneously arranged :—



for the α-hydrogen atom of acetals is very easily substituted. It may with confidence be anticipated that the corresponding hydrogen atoms in amines will prove to be similarly reactive—

$$\begin{array}{ccccccc} \mathrm{H} & - & \ddot{\mathrm{C}} & - & \ddot{\mathrm{C}} & - & \mathrm{N} < \\ + & & - & & + & & \underset{\cdot}{-} \end{array}$$

In illustration of the wide application of the principles which the writer conceives to be associated with atoms capable of inducing or affecting intramolecular polarisation, reference may be made to the three isomeric cresols. In these the influence of the hydroxylic oxygen as "key-atom" on the hydrogen atoms of the methyl group will evidently be such, if anything, as to increase their "positiveness" in the homogeneous *m*-cresol and to depress it in the heterogeneous *p*- and *o*-cresols. The influence of the methylic hydrogens, acting as "key-atoms," on the hydroxylic group, is as indicated in the generalised scheme—



The enhanced degree of polarisation, $-\overset{-}{O}-\overset{+}{H}$, in the hydroxyl groups of the homogeneous *m*-cresol contrasted with the opposite effect in the other two isomers, indicates that *m*-cresol is the most acidic of the three; in *o*-cresol the proximity of the $-OH$ group to the "key-atoms" suggests that in this compound their depressant influence will be more marked than in *p*-cresol. This arrangement, *m*-, *p*-, and *o*-cresol, in descending order of acidity, is precisely what is found to hold good. (Dawson and Mountford, *Trans. Chem. Soc.*, 1918, **113**, 987.)

Comparison of the cresols with phenol is not admissible, as the general basylous effect of methyl as compared with hydrogen would have to be taken into consideration, just as, for example, would have to be done in comparing acetic acid with formic acid; in both cases methyl depresses the acidity.

Whilst the principle of induced alternate polarities serves to group together a large number of otherwise apparently disconnected data, it is likely to remain comparatively infertile unless considered in conjunction with more purely chemical features, and especially with the question of free, partial and latent valencies and their interactions of which conjugation may be specified as a type.

In past years the writer endeavoured to develop schemes for reactions of carbon compounds on the assumption that those reactions were usually ionic in character. A mass of evidence has accumulated during the intervening years which tends to show that even those changes which in the main proceed through the ions have a parallel non-ionic course also, and that frequently the two proceed simultaneously and with the same end results, polarity considerations evidently affecting both identically. In seeking schemes to represent the course of such changes the writer holds that it is most satisfactory to seek first an explanation of the reaction in its ionic phase and subsequently to deduce the scheme for the reaction between the non-ionised components, the advantage of this course being that in nearly all instances only one of the radicles (or ions) of the electrolyte is chemically active and the ionic reaction must involve this one only at the critical stage—for example, OH' in alkaline saponification and CN' in cyano-hydrin formation. These ions are weak in comparison with, say, NO_3'; they have therefore less tendency to a stable diffuse distribution of their valencies, and tend to lose their ionic state by concentrating their diffuse valency on a single atom of another substance, especially if that atom itself has a decided polar character, inherent or induced. So, for instance, $H{\cdot}CN$, $H{\cdot}SO_3H$, etc., do not unite with an ethylenic bond, unless this is polarised as in $\alpha\beta$-unsaturated ketones, and are thus distinguished from $HO{\cdot}Cl$, $ON{\cdot}NO_2$ and Br_2, for example, which frequently attach themselves to non-polarised ethylenic bonds.

In order to indicate, necessarily very crudely owing to considerations of space, how the writer conceives these various aspects to contribute to the mechanism of chemical changes, he has selected three cases to which he attaches special interest. In the diagrams used he has followed Robinson in dividing a distributed valency into fractions, usually three, which total to the exact value of the single undistributed valency. A single valency is as usual indicated by an uninterrupted line and the fractions by dotted lines. The "latent polarities" of the atoms are indicated by the signs + or −, so that a molecule is electrically neutral when an equal number of free valencies proceed from positively and negatively polar atoms, while an ion has an excess of free valencies (which total to a whole number) proceeding from atoms of the one kind.

The first case is that of the formation of acetonecyano-hydrin which must be conceived as due either to the formation of a complex ion, from cyanion and acetone, or by direct addition of a metallic cyanide to acetone (compare *Trans. Chem. Soc.*, 1903, **83,** 100; 1904, **85,** 1206. *Zeitsch. Electrochem.*, 1904, **10,** 582). The cyanidion, Cy, in *Fig.* 1 is represented with a diffused valency which passes into space, to the solvent or to surrounding kations. The reactive phase of the acetone molecule is indicated with equal quantities of + and − partial free valency and consequently as electrically neutral; the arrangement of free partial valencies by which it attracts agents is precisely as conceived by Thiele. The stages (*b*) and (*c*) are intermediate types of univalent negative ions with diffused valency and lead to (*d*) which is the normal ion of the potassium derivative (*e*). (The metal derivative has been shown to be the intermediate compound in the formation of cyanohydrin from benzaldehyde and from camphorquinone. Compare *Trans. Chem. Soc.*, 1904, **85,** 1208 and 1210.)

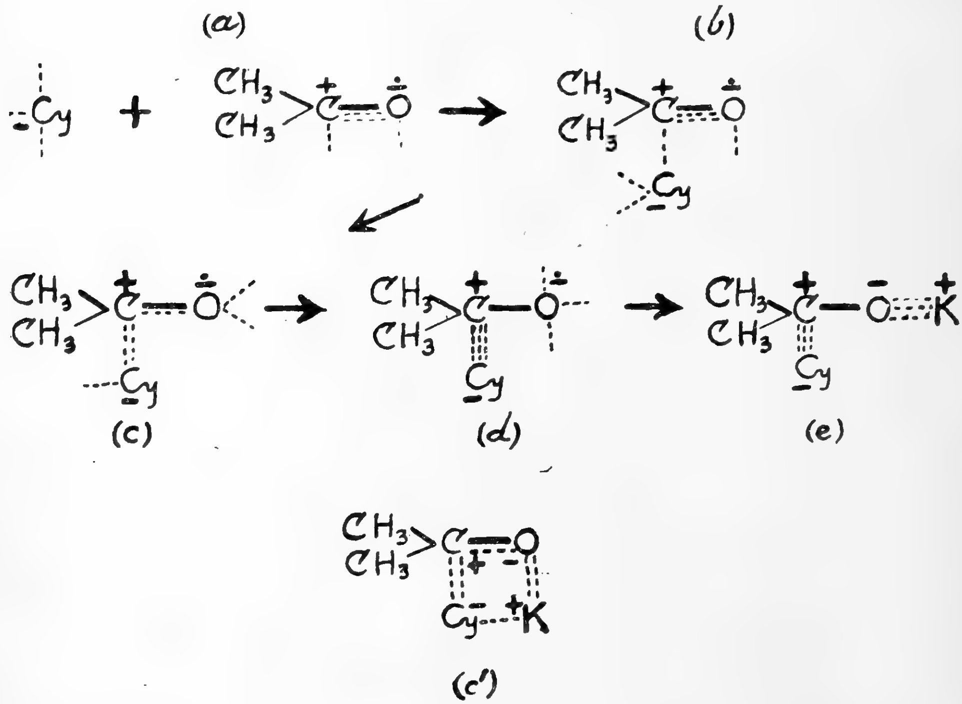
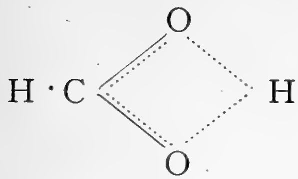
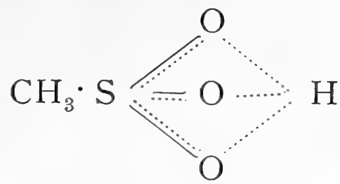


Fig. 1.

The expression (c′) in *Fig.* 1 represents the non-ionic phase corresponding with (c) and is consistent with the tendency of powerful ions such as K· to exercise their valency in diffuse form (compare Briggs, *Trans. Chem. Soc.*, 1908, **93,** 1564; 1917, **111,** 253; 1919, **115,** 278). In the same connexion it is worthy of note that most of the more powerful acids, and possibly all acids, are those in which the structure of the anion provides the possibility of such a diffuseness of valency.



Formic acid.



Methanesulphonic acid.

The formula for the carboxyl group, in the first of these, is identical with that proposed by Hantzsch, and is for the foregoing reasons eminently acceptable.

In *Fig.* 2 are indicated the stages which the writer conceives to represent the conversion of the ketonic group (i), into the ion (vi) of the *enolic* modification by the influence of hydroxyl ions. It can be shown that any view involving the assumption of addition of hydroxylion to the carbonyl group would not be helpful, as this occurrence would rather tend to weaken attachment of the bond between the two carbon atoms and to strengthen the attachment of the hydrogen atom; this course is doubtless what is followed during, for example, the alkaline hydrolysis of acetoacetic ester. The dissolving in alkali of the *ketonic* form of a substance (as the sodium salt of the *enol* form), is easy to understand when the principle of "induced alternate polarities" is considered in conjunction with a very natural extension of Thiele's theory of partial valencies.

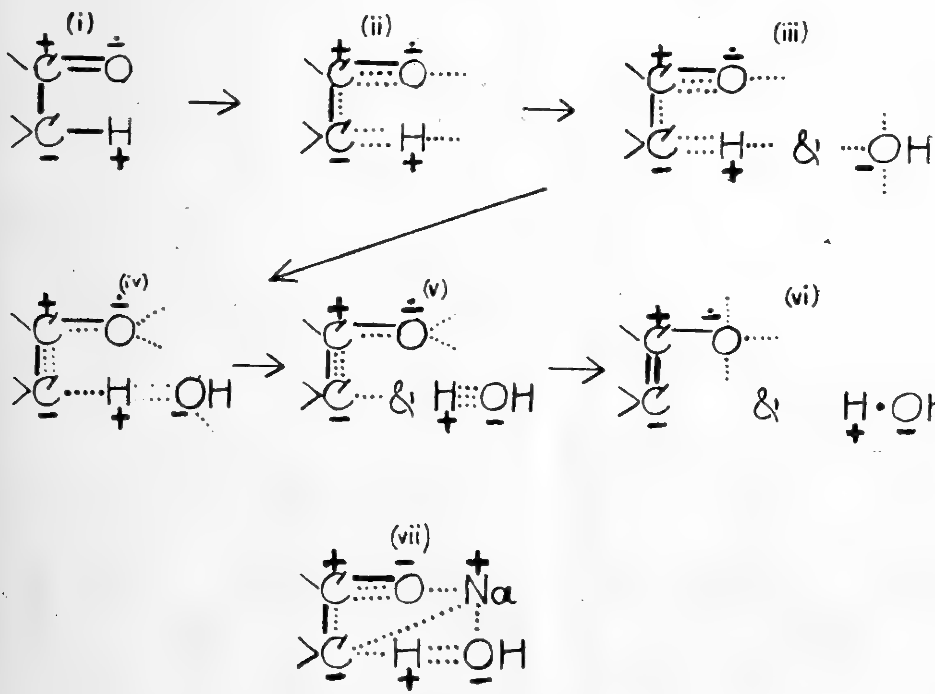
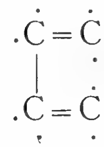
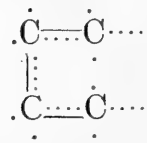


Fig. 2.

The ketonic form (i) is devoid of acid properties, or, in other words, the hydrogen atom is not directly ionisable. Under the influence of the "key" oxygen atom, however, it is endowed with some additional positive polarity. In the structure (ii) we have a rearrangement of the partial valencies analogous in all fundamental respects to Thiele's expression for conjugated systems, the relation between (i) and (ii) being the same as between

 and 

In (ii) the hydrogen atom attains only what may be termed incipient ionisation (in other words, a polar character with partially diffused valency), but in virtue of this is able to attract the negative hydroxyl ion. The subsequent changes leading to the formation of non-ionised water and the kation of the enol form in (vi) are now obvious.

No difficulty whatever is found in figuring the non-ionic analogue of any of these stages. Thus (vii) may be developed as the non-ionic form of (iv); and here again the diffuseness of the partial valencies of the metallic radicle and the acid radicle is consistent with what has been emphasised in the preceding paragraphs.

The formulæ given in *Fig.* 3 illustrate as fully as can be done within a limited space some of the applications of the principles in the aromatic series.

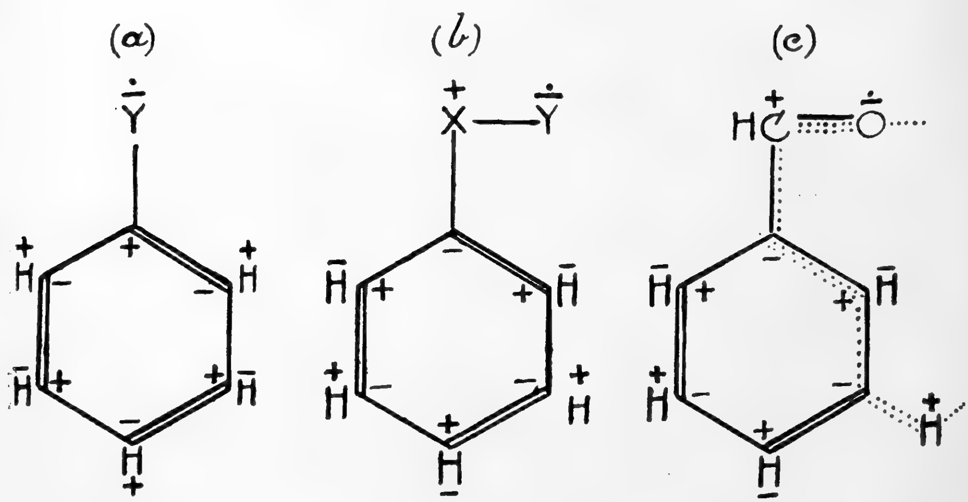
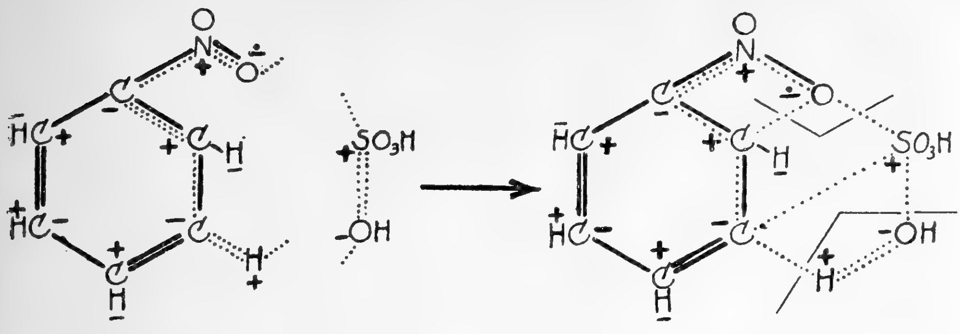


Fig. 3.



(i) (ii)

Fig. 3 *continued.*

The formula (*a*) is a type of *mono*-substituted benzene derivative which gives mainly *o*- and *p*-*di*-derivatives on further substitution, and Y may be *di*-valent $\overset{\dot{-}}{\mathrm{O}}$, *ter*-valent $\overset{\underset{.}{-}}{\mathrm{N}}$, halogen, etc. On the other hand (*b*) is the type which mainly yields larger quantities of *m*-*di*-derivative, and here Y may be the *di*-valent O of $>\mathrm{C}\overset{\dot{-}}{\mathrm{O}}$ or $>\mathrm{N}\overset{\dot{-}}{\mathrm{O}}_2$, the *ter*-valent N of $-\mathrm{C}\overset{\dot{-}}{\mathrm{N}}$, the halogen of quaternary ammonium salts, $-\mathrm{N(CH_3)_3.}\overset{\dot{-}}{\mathrm{Cl}}$, or of $-\mathrm{CH}\overset{\dot{-}}{\mathrm{Cl}}_2$ or $-\mathrm{C}\overset{\dot{-}}{\mathrm{Cl}}_3$. In the case of toluene it is not improbable that the hydrogen of the methyl group is the " directive " or " key " atom, so that in addition to (*a*) and (*b*) it may be necessary to add a third type with $-\overset{-}{\mathrm{Y}}-\overset{+}{\mathrm{X}}$, as side group with *o*- and *p*-directive influence.

Schemes very similar to (*a*) and (*b*) have been used previously by Fry, Vörlander and others, but with less stress on the influence of the " key " atoms as the paramount one; moreover, when Fry attaches alternating + and − symbols to successive atoms he does so on an *ad hoc* basis and is at no pains to show that this alternation is so general as the present writer has attempted to demonstrate. The principle of alternating latent polarities does not appear to follow from Thomson's theory of a bond, and Fry's formulæ are often wholly at variance with the principle in question.

The writer raises the case of *meta*-substitution in some detail, as he drew attention to its connexion with the case of α-substitution in the fatty series many years ago. Formula (*c*) in *Fig.* 3 represents his conception of the reactive phase of the benzaldehyde molecule preparatory to attack by a substituting agent in the *m*-position; comparison of this formula with (ii), *Fig.* 2, will make the exact analogy clear.

The corresponding phase of nitrobenzene prior to attack by sulphuric acid is shown in (i), *Fig.* 3; any process of normal substitution of $\overset{+}{\mathrm{H}}$ in this phase by $\overset{+}{\mathrm{SO_3H}}$ must give rise to the *meta*-sulphonic acid. Formula (ii), *Fig.* 3, represents a hypothetical stage in the intermediate compound which, by breaking down in the manner indicated, gives nitrobenzene*meta*sulphonic acid and water. Attention may be drawn to a figure which was developed by the writer in 1898 (*Trans. Chem. Soc.*, 1898, **73**, 456) in order to account for *meta*-substitution in nitrobenzene; the older figure is in all essentials wholly consistent with the one given above. In (ii), *Fig.* 3, the identity of the intermediate stages involved in direct sulphonation in the nucleus and in migration of the SO_3H from a hypothetical position on the O atom of the nitro-group to the *meta*-position, is most clearly suggested; with the introduction of the conception of partial valencies, however, the need of representing the *meta*-carbon atom as strictly doubly bound at any stage to each of two others as in the earlier explanation no longer exists.

In the preceding pages the writer has endeavoured to demonstrate the generality of the principle of alternate latent polarities as set by a "key atom." He has made no attempt to account for the principle, which at least is certainly not a consequence of Thomson's theory of the bond, but is possibly a mathematically necessary corollary of the mechanism of chemical change as regulated by the requirements of constant valency. For the present he is content (1) to have demonstrated that the generality of the principle is independent of hypothetical considerations, and (2) to have indicated a number of applications of the principle which may prove fruitful in suggesting new lines of investigation.

In taking the present opportunity of outlining his views on the questions of latent polarities and mechanism of reaction, the writer is conscious that these views have to a large extent been built up by the selection from many sources of ideas which appeared to be helpful in developing the generalisations to which he drew attention in 1898 (*loc. cit.*) and 1901 (*Trans. Chem. Soc.*, 1901, **79**, 1265 *et seq.*). Thiele's views have since virtually determined the lines of development of the valency aspects of organic chemical theory, but the writer has also been greatly influenced from time to time by the work of Hantzsch and Flürscheim, and of late by those especially of Briggs and of Robinson, to each of whom acknowledgments are due.

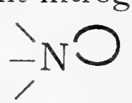
Manchester Memoirs, Vol. lxiv (1920), *No.* 4

IV.—The Conjugation of Partial Valencies.

By Professor Robert Robinson, D.Sc., F.R.S.

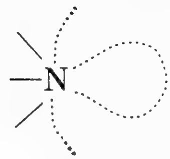
(Read March 16th, 1920. Received for publication August 9th, 1920.)

During the past five years the author has made use of a hypothesis which has appeared to simplify the representation of the possible mechanism of reactions in certain isolated cases, and the object of the present communication is to indicate some of the lines along which the theory may receive more general application. The necessary condition precedent to chemical change is assumed to be the "activation" of one or more of the molecules taking part in the reaction; this is followed by cohesion and rearrangement of valencies, most probably synonymous with changes in position of electrons. The result is either molecular rearrangement, the formation of an additive product or of new substances by fission of the complex. The activated molecules are further assumed to be polarised and to contain partially dissociated valencies. Thus H – Cl is supposed to be chemically inert, the molecule absorbs energy and becomes . . . . H . . . Cl . . . which is the reactive form termed partially dissociated because it is a stage towards complete ionisation. In thus splitting a valency it is always understood that the two or more dotted lines, though not necessarily themselves of equal value, are quantitatively equivalent in the sum to the normal unit valency from which they have been derived and the polar character of all these fractional valencies is identical. It is possible to allocate definite signs to the partial valencies in most cases as the result of a consideration of the relative polarities of atoms evinced for example in the limiting case of true electrolytic dissociation. A significant exception to the rule that partial valencies of similar sign emanate from the same atom at the same time exists in the case of those elements which exhibit latent valancies such as trivalent nitrogen. A neutral nitrogen atom is represented thus:—



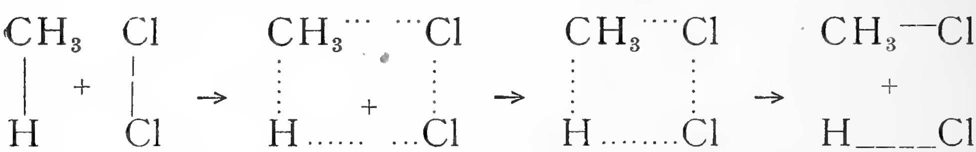
March 22nd, 1921.

and the loop, it is supposed, can be opened up in stages with the result that two partial valencies of opposite sign are produced. This condition of affairs may be expressed by the symbol :—

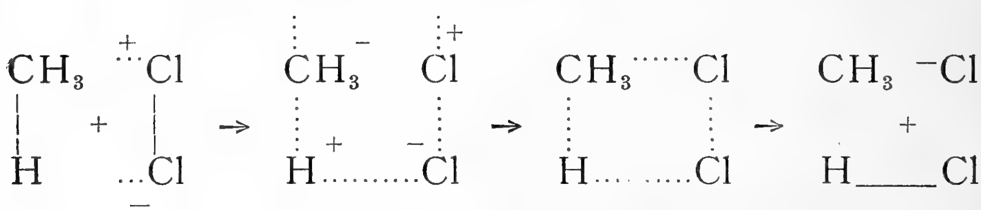


The chlorination of methane may be given as a simple illustration of the representation of a reaction in accordance with the above postulates :—

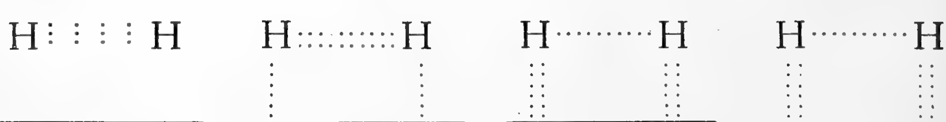
(A). *Reaction between two activated molecules.*



(B). *Reaction between an activated molecule and a neutral molecule.*



In passing it may be remarked that the rôle of a catalyst must very often be to produce activated molecules by the formation and subsequent decomposition of additive complexes. Thus in catalytic hydrogenation the hydrogen may be able to form a loose addition compound with nickel or palladium by the aid of a degree of dissociation so small that reaction with a substance containing an ethylene linkage cannot be effected. This compound on decomposition, however, may be assumed to liberate a strongly polarised hydrogen molecule, which is highly reactive and is capable of direct union with unsaturated substances.

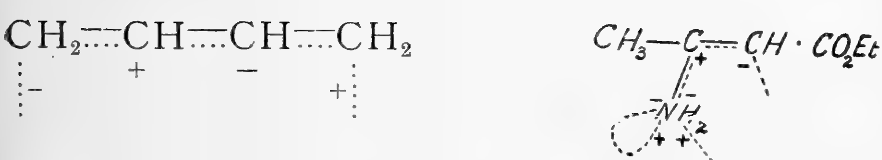


(Catalyst surface)

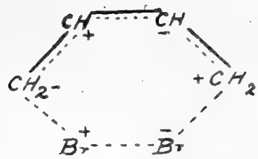
The representation of the phenomena of conjugation and addition to conjugated systems is much simplified by the use of the theory of divisible and polar valency and the definition of a conjugated system may be widely extended when the matter is considered from this point of view. Conjugation is the transfer of a free partial valency to an adjacent atom or to the end of a chain of atoms—it is the explanation of action at a distance in a molecule. The most elementary case may be exemplified by the scheme B above where the disturbance of the valency of a hydrogen atom of methane, due to the proximity of the reactive chlorine, involves the carrying through of this effect to the carbon atom and the appearance thereon of a negative free partial valency. There is clearly no definite limit to this process, but it is certain that the larger the number of saturated atoms in a chain the weaker will be the effect which can be carried through. The facts in relation to the azo-dyes which are substantive to cotton suggest the existence of very long conjugated chains in which all the atoms are unsaturated. A conjugated polarised complex capable of taking part in reactions must clearly have free partial valencies of opposite sign and the chain must accordingly comprise an even number of atoms, the exception being those systems which contain a nitrogen, oxygen or sulphur atom in which part use is made of the latent valencies. The even and the odd membered conjugations are shown below, the examples chosen being butadiene and ethyl β-aminocrotonate.

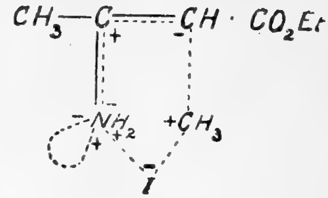
$CH_2=CH-CH=CH_2$

$$\begin{array}{l} CH_3-\underset{\displaystyle NH_2}{\underset{|}{C}}=CH\cdot COOEt \end{array}$$



It is convenient to classify as "primary" those conjugated systems or partially dissociated complexes which take part in reactions characterised by addition at the ends of the chain. Thus, in reacting with bromine, butadiene undergoes a primary conjugation of its partial valencies, and the same is true of ethyl-β-aminocrotonate in reacting with methyl iodide.*





↓ ↓

$Br-CH_2-CH=CH-CH_2-Br$

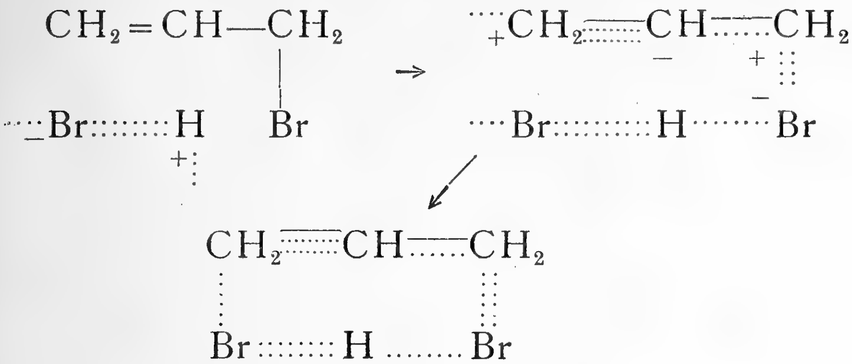
$CH_3-C-CH\cdot CO\,O\,Et$ ($C=NH_2I$, $CH-CH_3$)

It is important to notice that in the series :—initial compounds, intermediate additive complex, final products, all the alterations of valency are progressive. Take, for instance, the bond connecting the two central carbon atoms of butadiene. In the additive complex this becomes a sesqui-valency and a double bond in the product, and a similar gradual change will be found to be true of all the valency rearrangements whether involving making or breaking of unions or the transformation of single into double bonds and *vice versa*. Therefore, by assuming the possibility of great subdivision of valency, all these reactions could be represented as being almost continuous and with many intermediate phases.

The recognition of primary conjugation is rendered difficult when fission follows addition although analogies are usually available to assist in the determination. Thus there can be little doubt, in the author's view, that the facile reactions of aromatic phenols and amines are due to primary conjugations involving the latent valencies of the oxygen or nitrogen in association with the unsaturated carbon atoms of the nucleus. (Cf. G. M. Robinson and R. Robinson, *Trans. Chem. Soc.*, 1917, **111**, 964.)

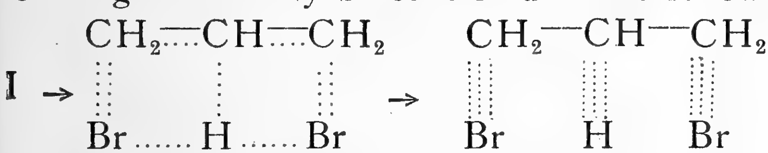
In "secondary" conjugation addition does not wholly occur to the ends of the system and the existence of the condition is usually recognised by an orienting effect. This will perhaps best be made clear by means of an example, the addition of hydrobromic acid to allyl bromide. (– = ┈┈).

* This is an unpublished observation made in collaboration with P. W. Denny and for further examples of this type of addition to a conjugated system Cf.—Decker, *Ber.*, 1905, **38**, 2893; Hamilton and Robinson, *Trans. Chem. Soc.*, 1916, **109**, 1029; Robinson, *ibid.*, 1039; G. M. Robinson and R. Robinson, *ibid.*, 1917, **111**, 958.



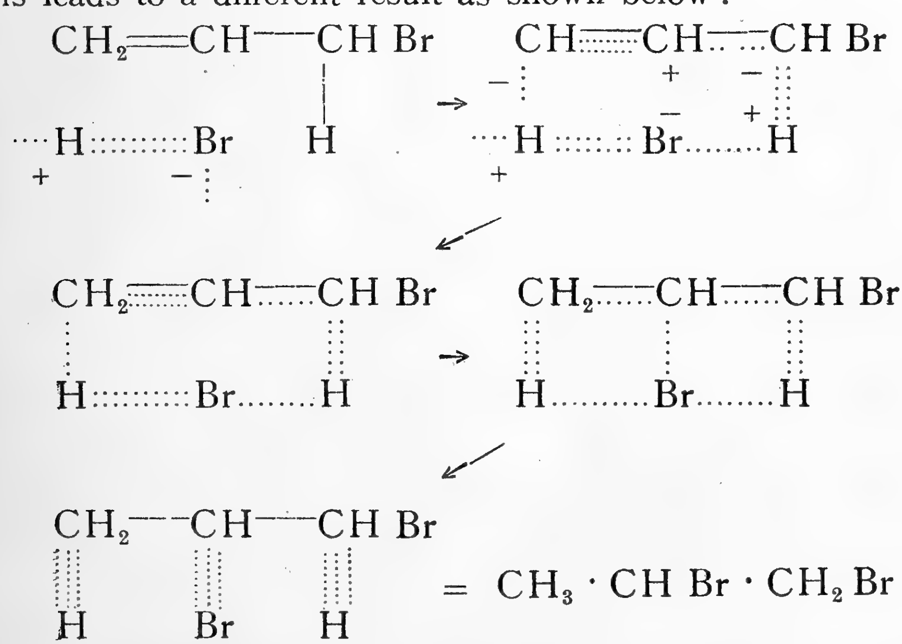
(I)

In the above scheme, the attack of the free partial valency of the hydrogen of hydrobromic acid on the bromine of allyl bromide induces a conjugation resulting in the appearance of a positive partial valency at the other end of the chain. Ring formation follows and the orienting effect is secured since the bromine is already partly attached to the position which it ultimately retains in trimethylene bromide. The further rearrangements may be conceived in the following manner:



$= Br\,CH_2 \cdot CH_2 \cdot CH_2\,Br$

On the other hand one of the hydrogen atoms of allyl bromide might be attacked by the bromine of hydrobromic acid and this leads to a different result as shown below:—



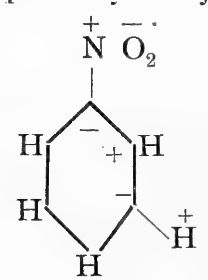
$= CH_3 \cdot CH\,Br \cdot CH_2\,Br$

A. F. Hollemann and B. F. H. J. Matthes (*Proc. K. Akad. Wetensch.*, Amsterdam, 1918, **21**, 90) have shown that in bright light allyl bromide absorbs hydrobromic acid with production of trimethylene dibromide, but that in the dark, although the latter remains the main product, considerable amounts of propylene dibromide are also formed. The present writer, in view of the simplification in expression, proposes to adopt the alternate labelling with + and − signs to denote the existence of secondary conjugation, and in accordance with Professor Lapworth's suggestion (this vol., Memoir No. 3, p. 5) the "key" atom may be indicated by an additional dot. Thus to follow out the examples already given, the secondary conjugations involved in the production of trimethylene bromide and propylenedibromide from allyl bromide are:—

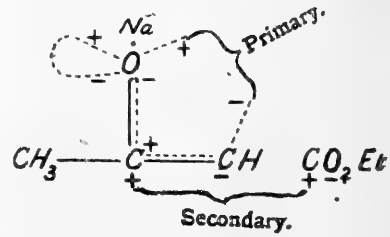
$$\overset{+}{CH_2}=\overset{-}{CH}\cdot\overset{+}{CH_2}-\overset{-\cdot}{Br} \text{ and } \overset{-}{CH_2}=\overset{+}{CH}\cdot\overset{-}{\dot{C}}HBr-\overset{+\cdot}{H}$$

respectively. Secondary conjugation is no doubt a widespread phenomenon. It is concerned in meta substitution in aromatic compounds and very frequently also reinforces the effect of a primary conjugation.

e.g.

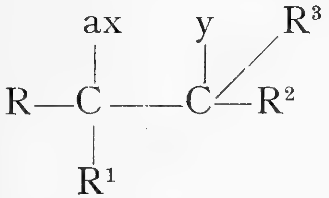


and



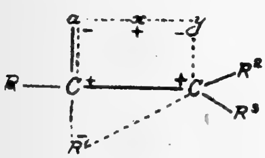
Examples of primary and secondary conjugations could be indefinitely extended, but it is not the present purpose to survey the field of organic chemistry from this point of view, but rather to indicate the general principles applicable to the symbolisation of the mechanism of reactions. There is, however, one group of reactions which occupies a somewhat special position, namely, those which involve molecular rearrangement. A theory of partial valency obviously offers scope for the explanation of such changes, which, it may plausibly be assumed, are in all cases due to an initial ring formation by the aid of fractional valencies. A generalisation of the transformation, of which the change of hydrazobenzene into benzidine is an example, has been discussed elsewhere (G. M. Robinson and R. Robinson, *Trans. Chem. Soc.*, 1918, **113**, 639), and it is of interest to note that the benzidine-type change in the glyoxaline series discovered by

R. G. Fargher and F. L. Pyman (*Trans. Chem. Soc.*, 1919, **115**, 217, 1015) is covered by the general statement and could perhaps have been predicted with its aid. All true intramolecular changes can be similarly generalised and the number of distinct types may be comparatively small. Reference may be made here to the dehydration of pinacone to pinacoline and that of borneol to camphene, two apparently dissimilar reactions which may nevertheless be brought under the same heading. In the expression

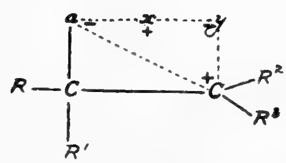


,

R, R^1, R^2, R^3 are neutral groups, *e.g.*, alkyl or aryl groups, *a* is a divalent atom or group and *x, y*, are monovalent atoms or groups of such a character that there is a strong tendency to form the compound *xy*. For purposes of convenience (and because it usually is so) *x* will be assumed to have electropositive character and *y* is electronegative. If *x* and *y* become attached by a partial valency then conjugation occurs and we have at once the conditions :—

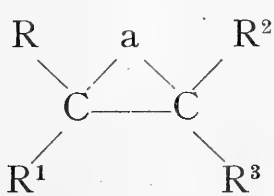


or



(A) (B)

since ring formation of the partial valencies is clearly impossible unless there are an even number of atoms in the ring. If now the process is continued in the same direction and the compound *xy* is separated, the result will be in case B that a three-membered ring will be formed :—



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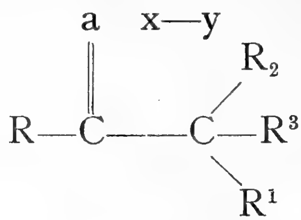
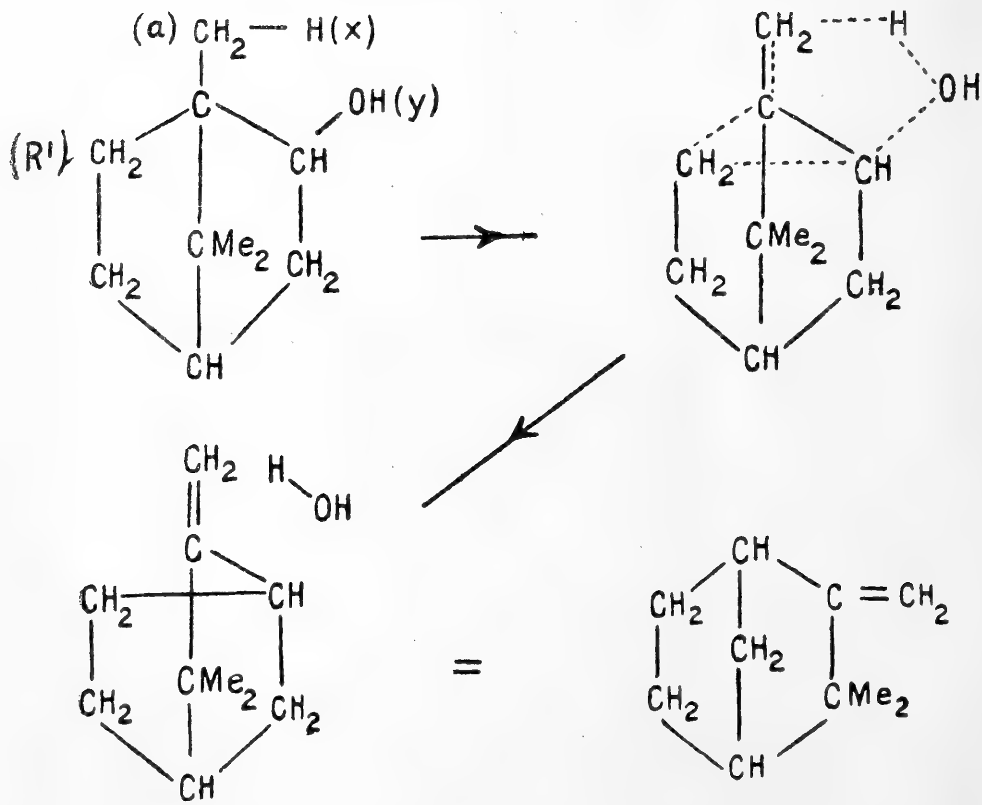
This occasionally happens, but in most cases the structure is unstable and undergoes ring scission under appropriate conditions reverting to the original substance or another compound resembling it in essential respects. Separation of *xy* from the complex A, however, involves the following result :



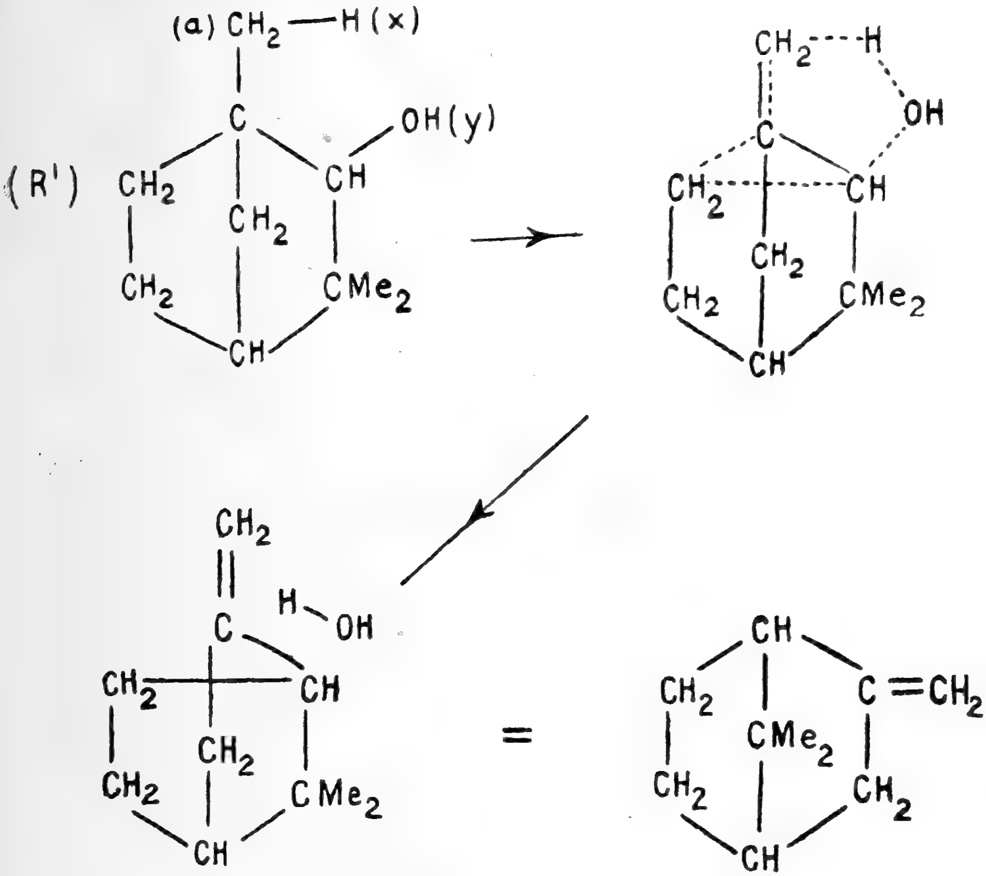
,

that is, the group R^1 is transferred to the adjacent carbon atom. In the pinacone-pinacoline reaction, *a* is oxygen, *x* is hydrogen and *y* is hydroxyl. In the borneol-camphene or Wagner rearrangement *a* is $-CH^2-$, *x* is hydrogen, and *y* is hydroxyl or a halogen atom. It will be found on inspection that a very large number of molecular changes, particularly in the terpene series, can be brought under the above generalisation. In view of the complexity of the formulæ the following examples may be quoted :—

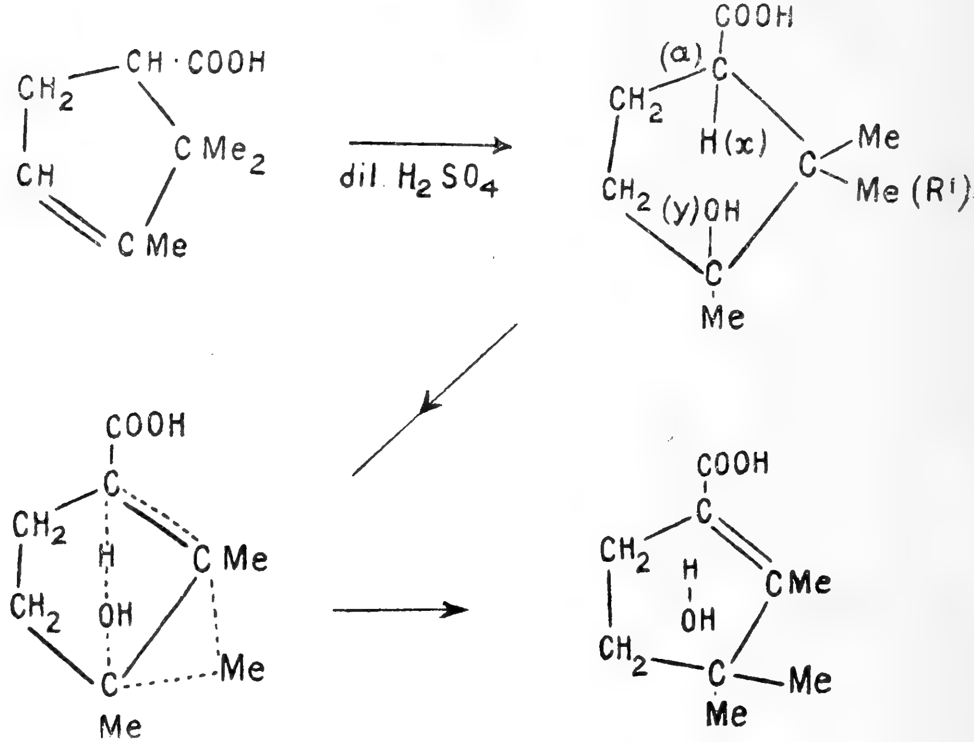
Borneol-Camphene.



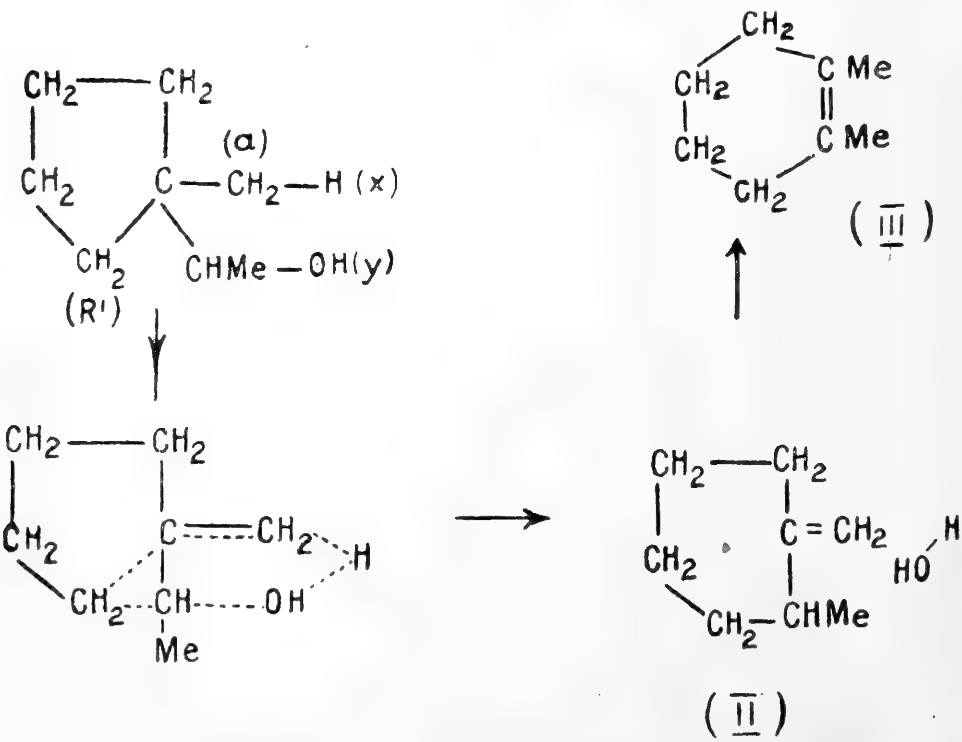
Fenchyl Alcohol-Fenchene.



α-Campholytic acid → β-Campholytic acid (isolauronolic acid).

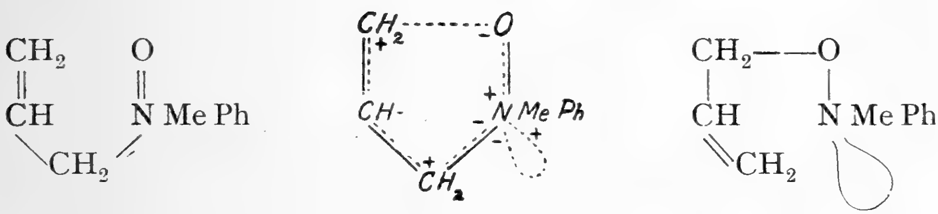


1-Methyl-1-α-hydroxyethyl*cyclo*pentane → 1.2-Dimethyl-Δ^1-*cyclo*hexene. (H. Meerwein, *Annalen*, 1918, **417**, 255.)



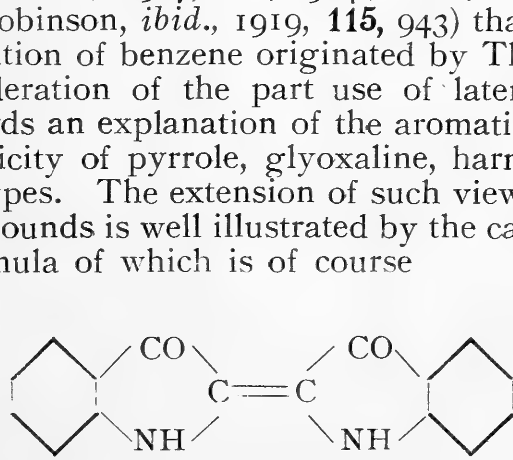
The product should therefore be the exocyclic hydrocarbon (II), whilst Meerwein actually isolates Δ^1-dimethyl*cyclo*-hexene (III). Under the conditions of the transformation the change of position of the ethylene linkage would, however, be anticipated.

Before leaving the subject of molecular rearrangement, an interesting recent observation of J. Meisenheimer (*Ber.*, 1919, **52**, (B), 1667) may be noted. Methylallylaniline N-oxide (IV) on distillation with a solution of sodium hydroxide in a current of steam is converted into the allyl ether of phenylmethylhydroxylamine (V). This reaction is interesting from the present point of view because, however regarded, it involves the formation of an odd-membered ring. This, as shown below, is rendered possible by the circumstance that a pentavalent nitrogen atom becomes trivalent in the course of the process.

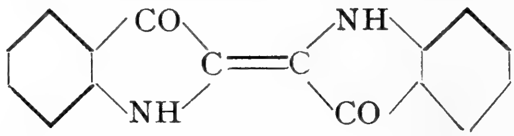


(IV.) (V.)

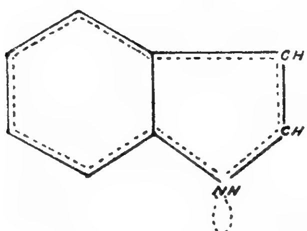
An almost inexhaustible subject for speculation is concerned with the existence of partial valencies and cyclic conjugation of partial valencies in normal molecules as distinct from those which are considered only at the moment of reaction. It has already been pointed out (G. M. Robinson and R. Robinson, *Trans. Chem. Soc.*, 1917, **111**, 964; *ibid.*, 1918, **113**, 640; Perkin and Robinson, *ibid.*, 1919, **115**, 943) that the theory of cyclic conjugation of benzene originated by Thiele, combined with a consideration of the part use of latent valencies of nitrogen, affords an explanation of the aromatic character and degree of basicity of pyrrole, glyoxaline, harmine and other heterocyclic types. The extension of such views to even more complex compounds is well illustrated by the case of indigotin, the usual formula of which is of course



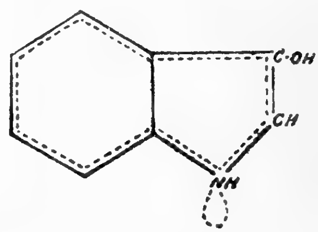
This expression as a vehicle for the explanation of the behaviour of the compound has grave defects, and, since the interpretation of the properties of the carbonyl group is very much a matter of opinion and relations of colour to structure still more so, the criticism of the formula may be confined to its failure to indicate the non-basic character of indigotin and the anomaly of the non-existence of cis-trans modifications. There seems to be no reason why the isomeride,



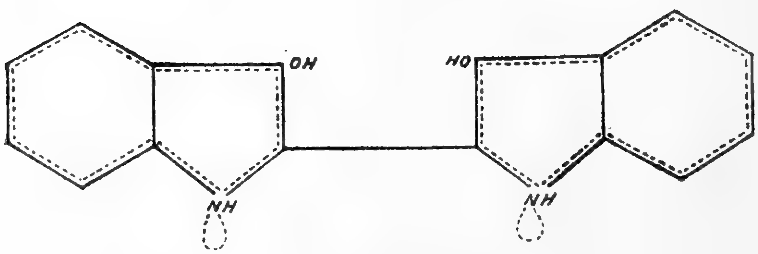
has never been isolated. All these and other objections are completely met by regarding indigotin as a true indole derivative. The series of formulæ now suggested are :—



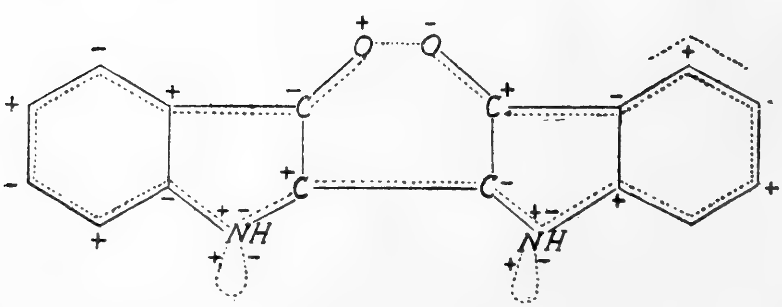
Indole.



Indoxyl.



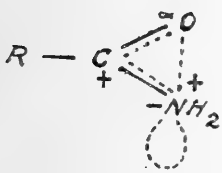
Indigo White.



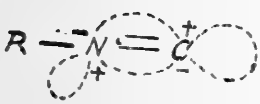
Indigotin.

On this view the oxidation of indoxyl with formation of indigo white resembles the oxidation of β-naphthol to dinaphthol, and the extremely ready reduction of indigotin is well explained by the peroxidic character of the substance. At the same time the nitrogen atoms are not capable of forming stable additive compounds and the possibility of cis-trans isomerism is not indicated. The aromatic cyclic conjugation embraces the whole molecule, the weakest link in the chain being the partial bond connecting the oxygen atoms.

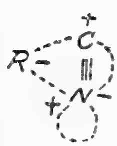
Of other partial valency formulæ the following may be put forward without further comment beyond the statement that the majority represent efforts to indicate the absence of basic properties in nitrogen compounds and that the formula for triphenylmethyl represents the third valency of the central carbon atom as taken up equally by the three nuclei each of which becomes partially quinonoid. Similar formulæ are possible for the rosaniline salts.



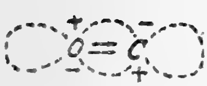
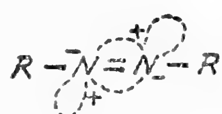
for acid amides and similar expressions for the carboxyl group and derivatives.



and

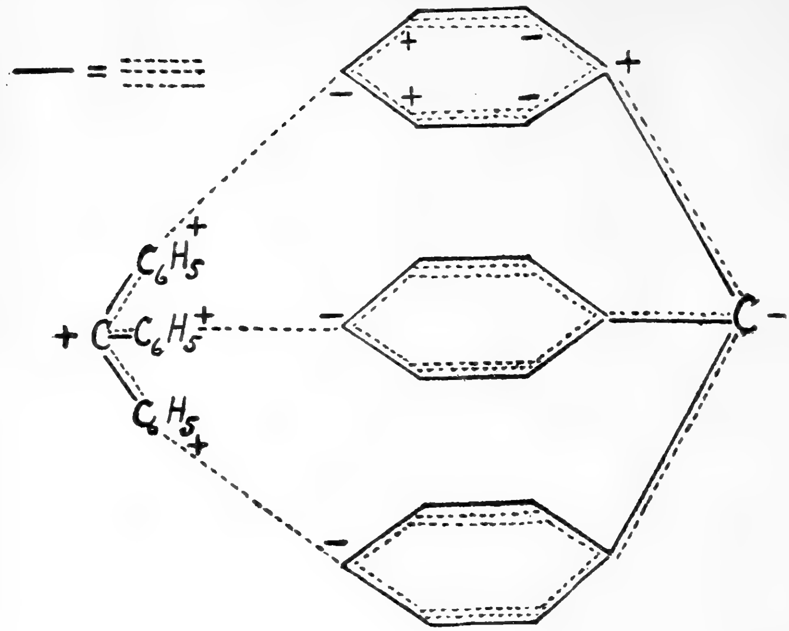


for isonitriles and nitriles respectively.

*  ,  ; and 

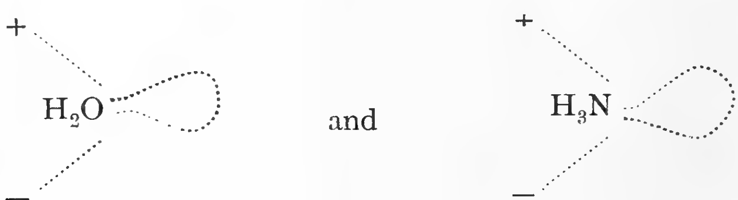
for carbon monoxide, nitrogen & the azo-compounds

*The decomposition, on heating, of ethyl oxalacetate into carbon monoxide and ethyl malonate provides an analogy to the separation of nitrogen from so many azo-derivatives.



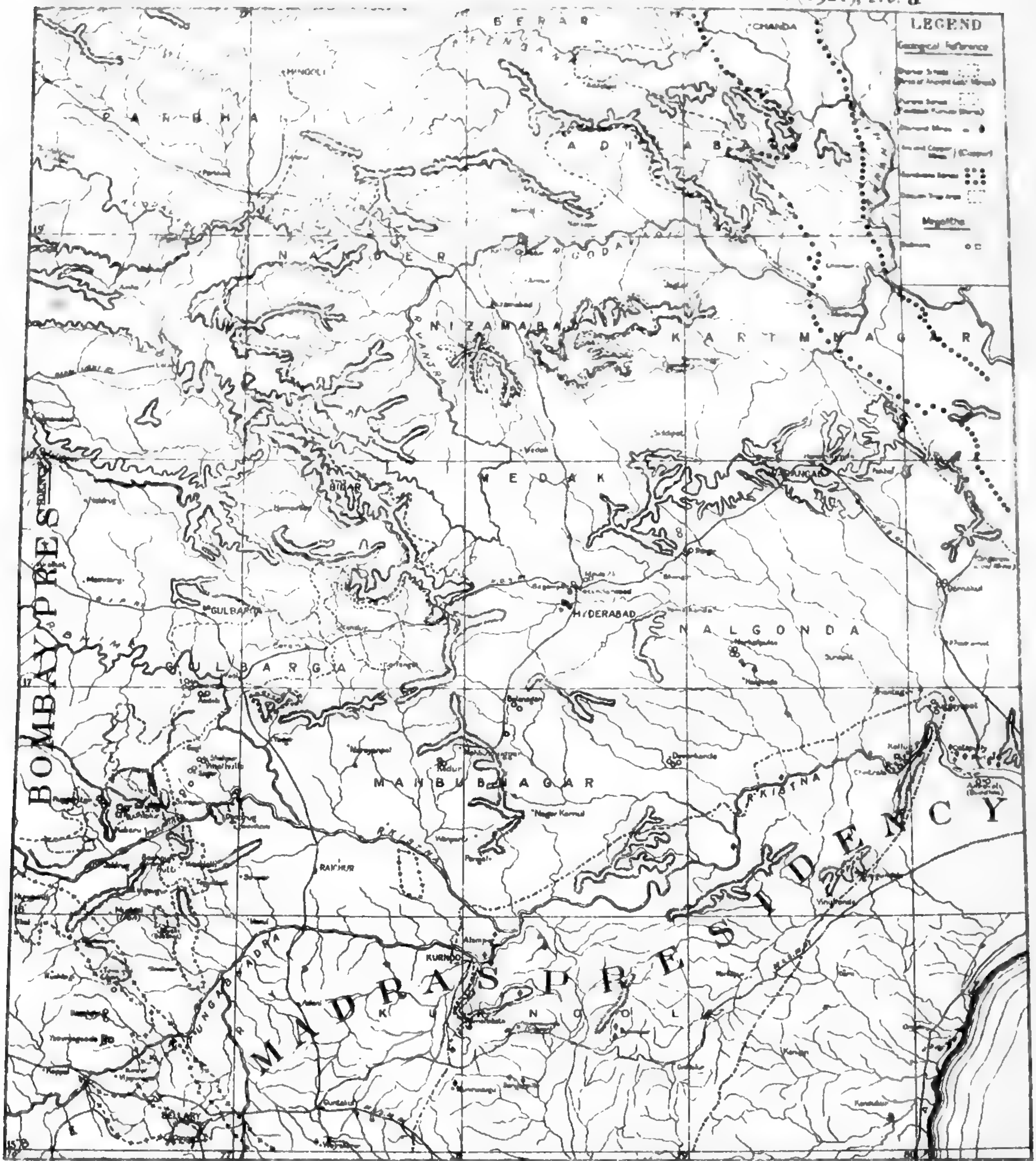
for
triphenyl-
methyl.

The explanation of the nature of loose additive compounds, such as the picrates of aromatic hydrocarbons, on the basis of the theory of divisible valency is so obvious as not to require further elaboration. Water of crystallisation and the ammonia of the metal-ammines no doubt involve the bipolar partially dissociated forms



with the aid of which it is possible to construct formulæ for hydrated salts and the most complex of the compounds now represented in accordance with Werner's co-ordination theory. The author gratefully acknowledges the influence of the writings of Werner, Thiele, Flürscheim, Decker, Kauffmann and particularly Lapworth, with whom he has had the great advantage of frequently discussing these and similar problems.

HYDERABAD, BOMBAY, BERAR
CENTRAL PROVINCES & MADRAS



Southampton Aug 7th 1917.

Drawn by Sapper S. J. Morgan R.E.

Southampton Aug 7th 1917.

Drawn by Sapper S. J. Morgan. R.E.

Scale 1/3,000,000 1 inch = 47·34 Miles

Miles 10 5 0 10 20 30 40 Miles

V. Ancient Mines and Megaliths in Hyderabad.

By Major LEONARD MUNN, R.E.

(Communicated by Prof. G. Elliot Smith, M.A., M.D., F.R.S.)

(Read February 5th, 1918. Received for Publication December 31st, 1920).

The object of this paper is to record some personal observations relating to the occurrence of dolmens, stone circles, and ancient mines, within the territories of H.H. the Nizam of Hyderabad.

In my capacity of Inspector of Mines to the State, I have had an exceptional opportunity of touring over and observing this country during the last 13 years.

The problem of the dolmens and stone circles is receiving the special attention of the Hyderabad Archæological Society, who will from time to time, in their journal, publish any new discoveries; so I will only attempt to plot on the attached map the position of the various groups of tombs known up to November 1915, and indicate the sites of the various classes of old workings.

The State of Hyderabad is about the size of Italy, and the dolmen remains, in comparison with the number of the cairns, are probably relatively scarce. I believe that the Bellary and Dharwar Districts, to the South of the Kristna River, will be found to contain many more dolmens than the whole of Hyderabad. Colonel Meadows Taylor reports 2,127 in Bellary District alone. Both these districts are riddled with old workings for gold, copper and iron.

The circled cairns, which are scattered in groups, sometimes numbering a few, sometimes thousands, all over certain geological areas of the State, are always found covering cists, containing uncremated and exceptionally well preserved human remains—iron implements—black and red pottery, sometimes of high finish but not decorated like that of the Nilghiris,—occasionally a bronze bell or a copper dish, and in rare instances, beautifully pierced beads of carnelian or *lapis lazuli*.

The stone circles are frequently found around the base of the "dome-shaped" protrusions of granitoid gneiss, which form such a noticeable feature of the Deccan Plateau, and apparently from all time have been held in reverence.

In all probability the cists, as Dr. Hunt observes, originally contained no filling—the silt which they now contain, the "Pandre-mutti" referred to by Colonel Meadows Taylor, being, no doubt, the result of infiltration of mud during successive monsoons. They are sometimes divided longitudinally into separate compartments, each containing a body.

Personally I have never come across any instances of burial such as Colonel Meadows Taylor found at Jewurgi, which led him to infer that human sacrifices were sometimes practised.

The manufacture of iron in the Deccan seems to have immediately superseded the Stone Age, the general use of high-class bronze and copper articles, some of which were found at Jaggayapet, in a grave, mixed with the bones of a horse, seem to be the product of a later age. The iron implements so far recorded, are spear heads, swords, sickles, iron stands for pots, and lamps. A careful analysis of some of these articles might afford an explanation why some implements have remained so wonderfully preserved, whereas others have become entirely unrecognizable through oxidation, though buried in the same grave.

In plotting the attached map I have classified all dolmens (whether circled, or free standing cromlechs or kistvaens) together, and used a separate symbol for cairns, whether with single, double, or triple circles. Even with the knowledge at present at our disposal, my map, I think, shows how closely they are associated with the sites of ancient mines.

There is little doubt that the plough is fast removing all these remains, and this perhaps explains why we generally find them on unculturable land.

No further discoveries of dolmens in the Raichur or Shorapur Districts have been recorded, though I am able to plot various localities where I have noticed stone circles, but which yet remain to be examined.

In 1904 I found a large group of dolmens of the open cromlech type at Chintrala in the South-East of the State, near the banks of the Kristna River, clustered around some old copper workings which I was examining. I reported them to the late Mr. Bruce Foote, and opening one, to find pottery and ashes, I took no further steps; and the group remains to-day untouched.

The local Brahmins raised no objection to my examining these graves, which they said were the homes of Rakshasa who were slain by Rama.[1]

Near the dolmens were what I took to be hut circles.

In the jungle near by, and all along the banks of the Kristna, are old diamond washing tanks, and heaps of river bed pebbles which had been carefully sorted in the method described by Tavernier.[2]

Further in the jungle I found some old terraces, showing previous long forgotten irrigation, of which there was no record on the Putwari's books.

So far as we know at present we have the following types of megalithic monuments :—

Dolmens. Free standing dolmens.
Holed kistvaens.

Circles. Circles around cairns with internal cists.
Circles around cairns with summit cist and internal cists.
Circles around dolmens.
Circles around menhirs or natural poised rocks.
Stone alignments.

It must not be thought that the attached map, in any way, defines the limits of the megalithic remains, or the ancient mining and smelting areas of the Deccan, save for spots I have personally visited along the borders of the State, I have confined myself to the area under my supervision.

1. My Brahmin clerk told me that one caste of blacksmiths still bury the cremated ashes of their dead in stone cists.

2. From this spot the cruciform shape of the quartzite ridge on the south bank of the Kristna below Mugetalah, mentioned by Tavernier, stands out with great clearness, and should remove any doubt as to which village is the Gani Kollur, to which he refers.

The geology of H.H.'s State can be divided into the following five main groups, which alone I have shown on my map; and for the sake of distinctness I have not attempted to outline the subdivisional groups.

*1. Archæan.	(*a*) Granite, granitoid gniesses veined with dykes of newer intrusive rock. Beds of iron ore	Area covered with tank irrigation.	Prehistoric iron mines over the entire area.
	(*b*) Dharwar Schists composed of hornblende and chloritic schists and epidorites and bands of hæmetitic and magnetite schist.		The gold bearing rocks of Southern India. Iron worked on the hæmatitic schists.
*2. Puranas (Vindhyan Rocks).	Limestones, quartzites, sandstones, slates and conglomerates.		The diamond and copper mines of Southern India.
3. Gondwana Series.	Sandstones and lacustrine coal beds resting on a glacial boulder bed.		Iron ores from each subdivision have been smelted. The area is mostly covered with dense forest.
*4. Deccan Trap and inter-trappean Beds.	The result of an enormous volcanic outburst in late cretaceous times which covers 200,000 square miles of India—during long quiescent period fresh water beds formed and were in turn covered by the trap.		Surface soil unsuitable for irrigation, remarkably few megalithic remains.
5. Cainozoic.	(*a*) Laterite.		Worked for iron.
	(*b*) Alluvial beds		Washed for diamonds in all streams and rivers which traverse the diamondiferous beds of the Purana series.

* See Sir Thomas Holland. "Gazetteer of India," Vol. I.

GOLD.

The area covered by the Dharwar Schists not only in Hyderabad State, but from Shorapur in the North, to the Waināḍ in the extreme South of India, is everywhere pitted with the remains of ancient gold mining, and, as far as I personally have seen in Hyderabad, around or in the vicinity of these workings, dolmens and circled cairns are to be found, and in Dharwar and Bellary even greater quantities are reported.

As far as Hyderabad State is concerned, the memory of the ancient gold mines and their workers seem entirely lost. I believe that this is true of the rock workings of Kolar, Dharwar and Rhodesia goldfields, though desultory washing for alluvial gold is recorded.

In Hyderabad one can obtain some idea of the possible date only through a process of elimination.

It cannot be possible that any gold mines existed in the days of the Vijjianuggur Kings, the wealth of whose kingdom was extolled by Ferishta, for sufficient time would not have elapsed to allow for the complete filling up and entire obliteration of all surface indications, of the huge pits which have since been unearthed, even if all memory of such an industry could be effaced in such a relatively short period. This is most unlikely, for the present inhabitant readily points out the iron mines, which still remain open, and records prove to have been worked at that period. Besides, the Raichore Doab has not been without its European Chroniclers, and neither Ferns Nunez or Paes ever mention the existence of gold mining. Nor in the great store of copper plate—or lithic records—which range through Mahommedan Chalukqan, back to the newly found inscription of Asoka, carved on a rock at Muski, in the middle of the auriferous band and surrounded by old gold workings, do we find a single reference.

Of folk lore there is none, else it must have come to the ears of Colonel Meadows Taylor, a man so loved and respected that his name yet lingers among the villagers and is recorded in song, which may still be heard, croned by some Beydur mother as she hushes her infant to sleep.

But beyond Professor Lassens' statement that the Sanskrit words, used in the Bible, had a Deccan termination, and on which he assumed that the land of Ophir was on the Malabar Coast, and that apparently unsatisfactory process of dissecting place names of the Doab, starting with the Sanskrit "Hoon" and generally terminating with either Persian or Canarese, no evidence of any gold industry can be found save a casual remark in Pliny ("Nat. Hist.," Book VI, chap. xx.).

It was, in fact, not until after 1888 that these old gold mines were rediscovered, and the early efforts of the explorers were watched with intense ridicule by the local Brahmin—who never had had clearer proof of the Sahib's madness. The difficulty which attended this prospecting was accentuated by the fact that all the workings had been completely filled up, and practically obliterated by the so-called black cotton soil—an al[illegible] resulting from the decomposition of the Deccan Trap. [illegible] at the surface indications were most deluding and consisted of shallow depressions, associated sometimes with chips of typical auriferous blue quartz, and the remains of old metallurgical appliances on the adjacent hard Trappoid rock. Costly excavations, therefore, alone could tell whether the site chosen was a series of rabbit warren workings, where the ancients followed some rich quartz leader, or whether a valuable pay chute was going to be disclosed.

The obliteration of all surface indications has been most tantalizing, and although the industry is represented at the moment by only one working mine, my confidence in the future discovery of other payable gold mines hidden below the black cotton soil plain is in no way shaken.

At Wondalli, Topaldodi, Oti Budini, Muski and Shorapur excavations of great age were opened up by the Hyderabad Deccan Company and its subsidiary companies. In each instance the ancients had extracted all payable gold to a considerable depth, and their methods of crushing were evidenced in the large grinders or rollers of hard trappoid or granite, which was rolled backwards and forwards in large hollows or saucers in the trappoid rock.

One of these "Mullackers" at Wondalli nullah must have weighed a ton, and was probably actuated by poles lashed to it. Everywhere cup-like hollows, undoubtedly nothing but small mortars found in the rock where the gold quartz was pounded with stone pestles and occasionally small crucibles have been found which, on crushing, gave an assay for gold.[3] Whether the miners possessed the knowledge of amalgamation is a moot point.

In the Hutti gold mines, discovered by Mr. F. W. Grey, we have the most extraordinary evidence of the skill of these ancient workers. There was little surface evidence at Hutti—

3. I have often wondered whether some of the "cup markings" reported by archæologists are not identical with these, and originally used for the same purpose. The Indian ryot recognises what they are, and even to-day uses them if they happen to be near his field.

a slight series of depressions—and here and there a few splinters of quartz which gave an assay—and the usual marks of crushing on the hard trappoid rocks near the Hutti nullah. Cross cutting exposed a long series of workings which were not bottomed by means of a small exploratory shaft. The Company was formed and deeper mining on a larger scale was undertaken, but the first attempt failed to bottom the old workings. Finally it was proved th[illegible] the ancients had excavated all payable quartz to an un[illegible]lleled depth of 640 feet. The presence of explosive gas—[illegible]ubt due to rotting timbers—and the expense that sp[illegible] through the loose material in the old stopes would h[illegible] cost prevented any extensive exploration of the old min[illegible]

Sufficient evidence was found to [illegible]te that the quartz reef was extracted by fire-setting—and after it was loosened was gouged out by iron-shod wooden levers. A great amount of timber had been employed; one piece might have been a windlass and marks on the "hanging wall" suggested the ore was raised by means of ropes. It was probably water that finally stopped the old workers from going deeper, for at 640 feet a large quantity of broken "chatties" were found, which suggested heavy bailing. No such instance of perseverance and skill has so far as I know been ever discovered in the other ancient mining centres at Kolar, Wainād, Dharwar and Anantagiri. The development of this mine must have taken a considerable period and employed a great number of people, not only in the actual mining, but in the crushing of the resulting ore.

I should like also to mention the ash mounds at Wondalli and Machnur. For a long time speculation attributed them to the slag, resulting from the refining of the gold or from glass making. Captain Newbold, who noticed some others near the so-called copper mountains, near Bellary, thought they were the remains of funeral pyres, and Mr. Maclaren, whose reports for the Geological Survey are so full of interest, gives the following assay, which he thinks upholds this theory.

	%
Moisture	0.26
Loss by ignition ...	3.39
SiO_2	66.19
CaO	15.88
Fe_2O_3 and Al_2O_3 ...	8.19
P_2O_5	1.57
Undetermined ...	4.52
	100.00

The Wondalli heap measures 150 ft. by 110 ft. by 25 ft. high and must contain 375,000 cubic feet, and is smaller than the one at Machnur. The mass is dull white to brownish in colour and here and there shows a certain amount of fusion.

It is unnecesary for me to give references to the Aryan habit of huge sacrifices, or to mention the custom of burning the dead on the battle field, but these mounds are of such enormous size that it is incredible that this could have been their origin. A few stone circles exist in the vicinity.

DIAMONDS.

Diamonds seem to have been worked in the Deccan from the earliest times, and it is only needful to mention the name of the old Hindu Capital Golconda (Kala Kandar) to recall the fame of the industry.

The diamond workings are of two classes—mines in the quartzites, sandstones and conglomerates of the Purana Group, and alluvial in the beds of rivers and streams which traverse those rocks.

It seems to be generally acknowledged[4] that India was the original source from whence the diamond came to the west and continued as the main supplier until the finding of the Brazilian mines.

As regards the ethnology of the miners, there is nothing to connect the earliest workings with Aryan influence; though in later times the Dravidian tribes became to a certain extent merged into the Hindu caste scheme—the industry remained in the hands of these outcasts to the present day.

On the accompanying map will be found most of the places made famous by Tavernier; besides those are marked some other spots where both alluvial and traces of pits, probably sunk in search of diamonds, have been noticed.

COPPER.

The large area of old copper workings, both in Hyderabad State and bordering the State to the South, are scattered over an area of apparently very low grade cupriferous slates. These workings were always a puzzle to me, until I hit upon the secret, by finding the village Dhobi at Chintrala beating out his Dhotti's on a slab of practically pure melaconite.

The ancients (at any rate in my district) carried out most extensive rabbit-warren-like workings in search of these pockets of high-grade ore, the product of surface enrichment.

4. See B. Laufer's report on "The Diamond in the Field." Columbia Museum (Chicago) reports.

I was able subsequently to find some of these pockets and some beautiful specimens were sent to the Madras Museum.

I found no trace of any smelting furnace, but saw a considerable amount of slag.

The copper mining in Hyderabad State in and around Chintrala is certainly very early, and, as I have already mentioned, so intimately associated with dolmen remains that, even in 1908, I had connected the two things together and never found them apart.

Iron.

Unless anyone has visited Hyderabad State, or in fact Southern India, they cannot get even a slight idea of the abundance, the extent, or the pureness of its iron ores. No section of the geological sequence exists in which iron does not occur. In the Archæn, magnetite most frequently occurs in almost unparalleled magnitude, whole hills and ranges being formed of the purest varieties; specular iron and red hæmatite are also found. The schistose area contains interbedded layers of magnetite and hæmatitic schists. The Purana Group contain veins of limonite and bedded magnetite. Nearly every group of rocks in the Gondwana system, save the bottom glacial beds, contain one or more of the ores of iron, in greater or less quantities. The disintegration of the Deccan Trap supplies rich pockets of magnetic iron sand that glisten in the beds of every stream that traverse that area.

Lastly the laterite is noted for its richness in this metal.

Each and all of these ores have been used for smelting iron by the natives. In this area iron has been known from earliest times, and the unintentional manufacture of steel practised.

Iron being found in such abundance on the surface, I cannot define any actual prehistoric mines, but the following centres of the industry have been always famed throughout India:—Nirmal, Hanumkonda, Warangal, Medak, Elgundal, Anantagiri, Nizamabad, Mudgal, Dekarkonda. They are indicated on my map. Of those I have mentioned, Nirmal is undoubtedly the most famous. Here steel has been made for unknown ages, and it has been a great trading centre for "wootz," right up to the nineteenth century, when Dr. Voysey found a Persian trader there from Ispahan purchasing the steel.

"The ore of this locality," writes Malcolmson (*Trans. Geol. Soc.*, Vol. V), "must be of exceptional quality, as otherwise it could not have retained its reputation as the best material for Damascus blades." It is near this village that

Fergusson notes some Christian crosses, lying near the dolmens. If he had only realized what a famous trading centre Nirmal District had once been he would have no difficulty in accounting for them.

Paithan in this district is mentioned by Herodotus.[5]

The Gondwana Series is contained within a long strip of country running parallel to the eastern boundary of the State. Save for a portion around the modern coal mine of Singareni it is almost unknown forest. Mr. Wakefield, the Director General of Revenue to H.H. The Nizam, has told me of wonderful old irrigation schemes, now out of use, within this region, and I have found areas of slag, proving old iron smelting sites, but I have never found any circles or dolmens. As soon as the war is over the revision survey of this area will be continued by the Government of India Survey, and it would be a wonderful opportunity to get, if they exist, the cairns and dolmens recorded, as well as those occurring in the remainder of Southern India.

The Deccan Trap contains no minerals of commercial value. It stretches over the whole northern and western portion of the State. At Tuljapur, Colonel Meadows Taylor reports a group of cairns near a rock temple, all associated with cremation, but beyond this I am unable to tell you of any other megalithic monuments situated within the geological area. Once the border between the Archæan and the Trap is passed the soil changes, and the black argillaceous soil of the Trap country is unsuitable for irrigation, which in this area is uncommon. The Trap area contains all that wonderful series of rock-cut temples—Ellora, Ajunta, Aurungabad, Nasik and Elephanta; and although these are of a later date than the monuments we are discussing, it is curious to note the Buddhists and Brahmins have each in turn chosen this rock in which to develop these marvels.

Before reading Professor G. Elliot Smith's and Mr. W. J. Perry's memoirs (in the *Memoirs and Proceedings* of this Society), having been so long accustomed to seeing terraced irrigation everywhere in Southern India, I had always taken it for granted that it was the natural product of a country whose total rainfall is limited to a few months of the year, whose surface contours make tank construction easy, and

5. About four years ago, the Taluqdar of Nizamabad sent to my office some fresh water pearls, collected from a mollusc in the fort ditch of Nirmal. I sent some of the shells to the Natural History Society of Bombay. I have never come across any other instances of fresh water pearls in the Deccan, and wondered at the time whether they could have been imported there at some period.

whose soil is specially suited to this class of agriculture. It is true that I had realized that this practice is practically unknown in Mahratwarra country to the north, but that is due to unsuitability of the Deccan Trap soil. Beyond this area to the north, where the Puranas and Archæan again appear, the custom of tank irrigation is not so prevalent. Irrigation is not a subject I am competent to discuss, but from my own observations I can state that here and there in the jungle are to be found remains of terraced irrigation of unknown age, well away from any village sites, and yet in no way differing from that still in use.

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PROCEEDINGS

OF

THE MANCHESTER LITERARY AND PHILOSOPHICAL SOCIETY.

Ordinary Meeting, October 7th, 1919.

Mr. Francis Jones, M.Sc., F.R.S.E., F.C.S. (*Vice-President*), followed by

Mr. William Thomson, F.R.S.E., F.C.S., F.I.C. (*Vice-President*), in the Chair.

A vote of thanks was accorded the donors of the books on the table. Mr. C. L. Barnes, M.A., drew attention to several works, including:—"*A Bibliography of Indian Geology and Physical Geography* . . ." (Parts I. and II.) by T. H. D. La Touche (8vo., Calcutta, 1917, 1918), presented by the Director of the Geological Survey of India; and "*Spencer Fullerton Baird—a Biography,*" by W. H. Dall (8vo., Philadelphia, 1915), presented by the Smithsonian Institution.

Gifts of a barometer, belonging to the late Dr. Henry Wilde, presented by Oxford University; a photograph of Dr. Henry Wilde, presented by Professor H. B. Dixon; thirty-two volumes of "*Memoirs and Proceedings,*" presented by Mr. John Boyd; and volumes 2-9 of the Society's "*Proceedings,*" from Mr. H. Crossley; were also recorded and votes of thanks passed to the donors.

An address on "**The Future of the Manchester Literary and Philosophical Society**" was given by Sir Henry A. Miers, M.A., D.Sc., F.R.S.

Sir Henry Miers referred to the discussion which took place on January 21st, 1919, at which it was proposed to make the Society more of a meeting place for persons generally interested in Science, and to give an opportunity for informal discussions. This was a work performed by such societies in their pioneer days; but with the increase of scientific knowledge the tendency has been for scientific people to segregate into special groups. As a result of this, the papers read at modern specialist societies are only calculated to appeal to experts.

A reaction is indicated by recent attempts at co-operation between the Humanities and Sciences, *e.g.*, in conferences, and the proposal for a common journal.

While nothing should be done to lower the tradition of the Society as a learned body promoting original research, it can do a great work by making the most recent advances in Science understood by those who are not experts, and by promoting joint meetings of various societies, at which new ideas can be expressed in language intelligible to all. Special lectures for working class audiences might also be instituted.

As the chief learned society in the district it is the natural convener of such conferences, through which it can counteract the present tendency towards specialisation of societies. There is danger of a scientific hierarchy, and of a cleavage between specialists and amateurs.

If investigators were encouraged in this Society to give popular expositions of their own discoveries to a general audience, in addition to the more severely scientific paper intended for publication, something would be done which has not yet been accomplished elsewhere.

The Society might also direct the attention of scientific workers of all sorts to problems which await solution, especially those which concern the Manchester district; and for this purpose bring other societies into touch with each other and with the University and College of Technology, and with the industries; acting as a sort of clearing-house by organising public lectures, special investigations, and other activities. In this way it might greatly assist the municipality by directing powerful intellectual forces to useful purposes.

General Meeting, October 21st, 1919.

Mr. WILLIAM THOMSON, F.R.S.E., F.C.S., F.I.C. (*Vice-President*), in the Chair.

Mr. FRANK LESLIE BARRETT, A.I.C., Research Chemist, Messrs. Tootal Broadhurst Lee Co. Ltd., and 15, *Russell Road, Whalley Range, Manchester;* Mr. JOHN HARRISON JAMESON, Engineer, 9, *Wilton Road, Chorlton-cum-Hardy, Manchester;* Miss MARY CUNNINGHAM, M.Sc. (Lond.), D.Sc. (St. Andrews), Research Chemist to the Fine Spinners' and Doublers' Association, Manchester, 6, *St. James's Square, Manchester;* Mr. HENRY STAFFORD GOLLAND, *Dunstan, Westminster Road, Eccles, Manchester;* Miss ALISON MCK. CRABTREE, Research Botanist, The Victoria University of Manchester, and 7, *Hague Road, West Didsbury, Manchester;* Miss M. I. MCCLATCHIE, M.Sc., Research Botanist, *The Manchester High School for Girls, Dover Street, Oxford Road, Manchester;* Miss ELAINE DE STE C. FOGG, B.Sc., Assistant Lecturer and Demonstrator in Botany in the Victoria University of Manchester, *The University, Manchester;* Mr. FREDERICK CHARLES WOOD, B.Sc. (Lond.), F.C.S., A.I.C., F.R.Met.S., Chemist, *c/o Messrs. Tootal Broadhurst Lee Co. Ltd.*, 56, *Oxford Street, Manchester;* and Professor T. H. PEAR, M.A. (Manc.), B.Sc. (Lond.), Professor of Psychology in the Victoria University of Manchester, *The University, Manchester;* were elected Ordinary Members of the Society.

On the Incorporation of the Manchester Chemical Club the following gentlemen were elected Ordinary Members of the Society:—

Mr. W. E. ALEXANDER.
Mr. MARCUS ALLEN, M.I.Mech.E.
Mr. E. A. ALLIOTT, B.Sc., A.M.I.Mech.E.
Mr. W. ANDREWS.
Mr. THOMAS ASPINALL, F.C.S.
Mr. S. S. AUSTIN.

Mr. JAMES BADDILEY.
Mr. H. J. BAILEY.
Mr. DAVID BAIN.
Mr. J. E. BALMER.
Mr. PERCY BEAN, F.C.S.
Mr. ERNEST BEARD,
Mr. A. W. BENNIS, M.I.Mech.E., A.I.E.E.
Dr. W. H. BENTLEY, F.C.S.
Mr. A. E. H. BLACKBURN.
Mr. JOSEPH BREWERTON.
Mr. J. H. BRIERLEY.
Mr. RAINALD BRIGHTMAN, M.Sc., F.C.S., F.I.C.
Mr. JAMES BRYANT.
Mr. G. A. BUCKLEY.

Dr. THOMAS CALLAN, M.Sc., F.C.S.
Mr. A. F. CAMPBELL, M.Sc., F.C.S., F.I.C.
Mr. DAVID CARDWELL, M.Sc., F.I.C.
Mr. C. W. CARPENTER, M.Sc.Tech., F.C.S., A.I.C.
Mr. JOSEPH CAUTHERY.
Mr. HOWARD CHEETHAM.
Mr. F. S. CHOATE.
Mr. W. H. COLEMAN.
Mr. J. A. COOMBS.
Mr. W. J. COOPER, F.C.S., F.I.C.
Mr. C. W. CRAWSHAW.
Mr. H. CRUSE.
Mr. P. CRYER.
Mr. J. B. CULLEN.

Mr. G. K. DAVIS.
Mr. H. E. DOUGHTY.
Mr. JOHN DOWNHAM, J.P.
Mr. WILLIAM DUCKWORTH.

Mr. H. J. EDGE.
Mr. JAMES EDGE.

Mr. WILLIAM FINLAY.
Dr. R. B. FORSTER.
Professor G. J. FOWLER, D.Sc., F.C.S., F.I.C.

Lt.-Col. EDWARD GARSIDE, B.Sc., M.Inst.C.E.
Mr. E. G. GAUL, M.Sc., F.C.S., F.I.C.
Mr. PERCY GAUNT.
Mr. S. W. GILLETT.
Mr. JAMES GRANT, M.Sc.Tech., F.C.S., F.I.C.
Mr. F. N. GRANT.

Mr. G. D. A. HALL.
Mr. B. H. HALSTEAD.
Mr. J. R. HANNAY.
Mr. J. H. HARGREAVES.
Mr. W. B. HART, F.C.S., F.I.C.
Dr. J. A. R. HENDERSON, F.C.S.
Mr. D. M. HENSHAW.
Mr. A. D. HEYWOOD.
Sir HENRY F. HIBBERT, Bart., J.P., F.R.G.S., F.S.S.
Mr. ANDREW HODGE.
Mr. T. R. HODGSON, M.A., F.C.S., F.I.C.
Mr. G. E. HOLDEN.
Mr. P. F. HOLMES, M.I.Mech.E.
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Mr. HENRY HUMPHREYS.
Mr. HARRY HURST,
Mr. J. E. HURST.
Mr. T. W. S. HUTCHINS.

Mr. WILLIAM INGHAM, M.I.Mech.E.
Mr. J. M. IRVING.

Mr. FREDERICK JACKSON.
Mr. R. H. JACKSON.
Mr. I. R. JONES.

Mr. W. E. KAY, F.C.S.
Mr. J. E. KEIRBY.

Mr. J. E. LEA, B.Sc., M.I.Mech.E.
Mr. J. H. LESTER. M.Sc., F.I.C.
Dr. HERBERT LEVINSTEIN, M.Sc., F.C.S., F.I.C.
Mr. K. H. LIVERSEDGE.
Mr. C. J. LOMAX, M.Inst.C.E., M.Cons.E.
Mr. ERNEST LONG, A.M.Inst.E.E.
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Mr. J. E. C. LORD.

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Mr. JOHN MACKAY.
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Mr. WILLIAM MARSHALL.
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Mr. W. H. ORMEROD.

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Mr. J. PAYMAN.
Mr. R. H. PICKLES.
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Mr. JOHN REID.
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Mr. A. E. ROYSE.

Mr. HAROLD SANKEY.
Mr. F. SCHOLEFIELD.
Mr. A. R. SCOTT.
Mr. W. E. SHELLEY.
Mr. R. DES F. SHEPHERD, B.Sc.
Mr. STANLEY SMITH.
Mr. JOHN SNOWDON.
Mr. CHARLES SPACKMAN, F.C.S., F.I.C.
Mr. C. R. SPACKMAN.
Mr. R. A. STURGEON.
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Mr. J. W. WELCH.
Mr. E. E. WIELER.
Mr. E. J. WILKINSON, F.C.S.
Mr. A. F. WILLIAMS.
Mr. H. E. WILLIAMS, F.C.S.
Mr. T. R. WOLLASTON, M.I.Mech.E.
Mr. W. W. WOODWARD.
Dr. W. WYLER.

Ordinary Meeting, October 21st, 1919.

Mr. WILLIAM THOMSON, F.R.S.E., F.S.C., F.I.C. (*Vice-President*), in the Chair.

A vote of thanks was accorded the donors of the books on the table. These included: "*Rats and Mice as Enemies of Mankind*" (Brit. Mus. Econ. Ser., No. 8), by M. A. C. Hinton (8vo., London, 1918), presented by the Trustees of the British Museum (Nat. Hist.).

Professor W. L. BRAGG, M.A., read a paper entitled "**Sound Ranging.**"

A sound spreads from the point where it originates as a spherical wave moving with constant velocity. If it is intercepted by three or more stations whose positions are accurately known, and if the time intervals elapsing between its arrival at the stations are measured, a simple construction gives the position of the source of the sound.

Soon after the commencement of hostilities it became clear that the struggle was going to take the form of trench-warfare. This gave rise to the idea of locating the enemy guns by sound in the way described above. The French made experiments with "Sound Ranging" in October, 1914, and showed that it was feasible, and the British Army was encouraged by their success to send an experimental Sound Ranging Section to the front. This section started operations in October, 1915, taking up its position opposite Wytschaete. At first the results obtained were poor, but they improved with experience and better apparatus. The original section became a training school for officers and men, and sufficient sections were formed to cover the whole of our front.

Each section had six microphones, spaced along a base opposite the German front line. The microphones were connected to a chronographic instrument at a central headquarters, and when the sound reached the microphone it sent an electric signal recorded by the instrument. In front of the base there were two observation posts so placed that the sound reached them a few seconds before it reached the microphones. This gave time for an observer at the post to press a key which started the recording apparatus at headquarters. By studying the record the time intervals could be measured and the position of the gun plotted on the map. This was then telephoned to the artillery.

There were between thirty and forty sections along the front. They could locate batteries between 10,000 and 15,000 yards away with a mean error of about 50 yards. An idea of the number of locations obtained may be gathered from the fact that each section sent in about one thousand results in the year.

The greatest difficulty was caused by adverse winds. If the wind were blowing from our side of the line towards the German batteries the sound never reached the microphones, being deflected into the upper air. This meant that in westerly weather Sound Ranging was of little assistance.

The results obtained by Sound Ranging and other means of location were used in the preparation of maps showing the positions of the enemy batteries. We did not always try to destroy an enemy battery which had been located, it was often advisable to find out as much as possible about it and leave it alone until occasion demanded that its fire should be neutralised.

Sound Ranging was a valuable means of getting information about the hostile batteries, and a very large proportion of the total number of locations were made in this way.

Towards the end of the war the sections were faced with the problem of moving their bases quickly to accommodate them to a front line which never remained in the same place for many days consecutively. They became expert in doing this and were able to give material assistance in the last stages of the struggle.

General Meeting, November 4th, 1919.

Professor F. E. WEISS, D.Sc., F.R.S., F.L.S., in the Chair.

At this General Meeting, summoned in accordance with the Articles of Association, an application having been received and approved by the Council for the formation of a CHEMICAL SECTION of the Society, the following resolution of the Council was submitted to the Society:—

> "That the Chairman and Secretary of the Chemical Section of the Society be added to the Council as *ex-officio* Members thereof."

This resolution was adopted.

Professor SYDNEY CHAPMAN, M.A., D.Sc., F.R.S., Professor of Mathematics and Natural Philosophy in the Victoria University of Manchester, *The University, Manchester;* Mr. W. H. PEARSON, M.Sc., A.L.S., 18, *Palatine Road, Manchester;* Mr. PERCY MCMICHAEL, Science Master, Central High School for Boys, Whitworth Street, Manchester, *Central High School, Whitworth Street, Manchester;* Professor W. J. SEDGEFIELD, M.A., Litt.D., Professor of the English Language in the Victoria University of Manchester, *The University, Manchester;* Professor MAURICE A. CANNEY, M.A., Professor of Semitic Languages and Literatures in the Victoria University of Manchester, and *Ingleside, St. John's Road, Knutsford, Cheshire;* Mr. NORMAN TUNSTALL, M.Sc., Lecturer in Physics, The Victoria University of Manchester, *The University, Manchester;* Professor A. J. TURNER, M.A., B.Sc., Professor in Textile Technology in the College of Technology, Manchester, *The College of Technology, Manchester;* Miss ALICE TABERNER, B.Sc., Research Student in Botany, The Victoria University of Manchester, *The University, Manchester;* Professor W. L. BRAGG, M.A., Langworthy Professor of Physics in The Victoria University of Manchester, *The University, Manchester;* and Dr. J. N. PRING, M.B.E., Lecturer and Demonstrator in Electro-Chemistry in the Victoria University of Manchester, *The University, Manchester;* were elected Ordinary Members of the Society.

Ordinary Meeting, November 4th, 1919.

Professor F. E. WEISS, D.Sc., F.R.S., F.L.S., in the Chair.

Professor WILLIAM H. LANG, M.B., C.M., D.Sc., F.R.S., gave a Lantern Demonstration on: **"One of the Simplest Land Plants,** ***Hornea Lignieri.***"

The Lantern Demonstration illustrated the further results obtained by Dr. R. Kidston and Professor W. H. Lang in the study of the silicified Old Red Sandstone plants at Rhynie, Aberdeenshire, now in course of publication by the Royal Society of Edinburgh. Two species of *Rhynia* are now distinguished: *R. Gwynne-Vaughani* and *R. major*. The latter is larger in all its parts than *R. Gwynne-Vaughani* and differs in some details of the anatomy. These plants are rootless and leafless and consisted of a subterranean rhizome with rhizoids, dichotomously branched cylindrical aerial stems and large terminal sporangia.

Another equally simple plant, associated with these in the Family Rhyniaceae, has been discovered and investigated. This is named *Hornea Lignieri* and consisted of rhizomes, branched stems, and terminal sporangia, without roots or leaves. The rhizomes were lobed parenchymatous structures, suggesting comparison with the protocorm of certain species of *Lycopodium*. The stems branched dichotomously, and had a simple central cylinder, cortex, and epidermis. No stomata have yet been discovered in this plant, as they have in *Rhynia*, but its organisation suggests a similar land-habit. The sporangia are remarkable in the presence of a columella-like central region making the spore cavity dome-shaped.

These simple Vascular Cryptogams suggest comparisons with Bryophyta and Algae.

General Meeting, November 18th, 1919.

Mr. William Thomson, F.R.S.E., F.C.S., F.I.C. (*Vice-President*), followed by Professor F. E. Weiss, D.Sc., F.R.S., F.L.S. (*Deputy Chairman*), in the Chair.

Sir Henry A. Miers, M.A., D.Sc., F.R.S., Vice-Chancellor of the Victoria University of Manchester, was elected *President* of the Society in succession to Professor G. Elliot Smith, M.A., M.D., F.R.S.

Following an announcement by Mr. William Thomson that Professor F. E. Weiss had, at the request of the Council consented to act as *Deputy Chairman* on such occasions as the *President* could not attend the Society's Meetings, Professor F. E. Weiss took the Chair.

Mr. Alfred John Pennington, Research Chemist, *Oakley, Fallowfield, Manchester;* Mr. Joseph Watson Lewis, B.Sc., Assistant Physicist, Messrs. Tootal Broadhurst Lee Co. L'td., 56, Oxford Street, Manchester, and 13, *Cawdor Road, Fallowfield, Manchester;* Mr. Alfred Charles Dunningham, D.Sc., F.C.S., F.I.C., Chief Chemist of the Electro-Bleach and By-Products Ltd., Middlewich, and *Ashville, Middlewich, Cheshire;* Mr. Thomas Lawrenson, Manager of the British Dye Stuffs Corporation, Ltd., Middlewich Branch, Middlewich, and *Plas Newydd, Croxton Road, Middlewich, Cheshire;* and Mr. James Booth Sharp, Aniline Colour Manufacturer, *Rookswood, Old Hall Road, Broughton Park, Manchester;* were elected Ordinary Members of the Society.

Ordinary Meeting, November 18th, 1919.

Professor F. E. WEISS, D.Sc., F.R.S., F.L.S. (*Deputy Chairman*), in the Chair.

A vote of thanks was accorded the donors of the books on the table. These included: "*A Subject Index to the Poems of Edmund Spenser*," by C. H. Whitman (8vo., New Haven, 1918), presented by the Yale University Press, New Haven, Conn.

Professor T. H. PEAR, M.A., B.Sc., read a paper entitled **"The Elimination of Wasteful Effort in Industry."**

The lecturer pointed out that, it being impossible to distinguish sharply between physical and mental effort, in the investigation of the problems of economising human energy physiology and psychology must work side by side. While in many industries improvement of the external conditions of work such as temperature, ventilation, humidity, illumination, was rapidly proceeding, less had been attempted in the direction of improving the methods of work themselves. Examples of such efforts illustrated the importance of certain fundamental principles. The first was the adjustment, both in total length and in distribution, of rest pauses. By introducing suitably chosen rest pauses and by modifying the working attitude of girls who were engaged in folding handkerchiefs, the output increased 300 per cent. while the folders worked only 45 minutes in each hour and were less fatigued than before. The second principle was the substitution of habitual movements for constant acts of decision. By rearranging the method of "assembling" a braid machine, so that the parts were not only put together in a more efficient order, but were more easily found by the workman, 66 units were assembled by a man in one day instead of 18. The third was the elimination of useless movement. By this means the separate actions required to lay a brick had been reduced from 18 to 5; the output increased from 120 per man per hour to 350.

Insistence was laid upon the importance of teaching the best methods of work first, before the worker had acquired less efficient methods which were difficult to unlearn, and upon the necessity of such training being carried out by persons who knew how to teach. By analysing the results of motion study in a British munition factory during the war and similar improvements elsewhere, it was shown that "speeding up," fatigue, and the exploitation of the worker are by no means necessary results of such modifications. The question of the monotony alleged to be caused by such "shorthand" methods of work was also discussed. The fundamental confusion between the terms "monotonous" and "habitual" was emphasised, and means were described by which the more efficient methods may increase interest in life both directly through their own nature and indirectly through the increased leisure, husbanding of energy and higher wages which they make possible.

In the discussion which followed, Dr. William Cramp, M.I.E.E., pointed out the dehumanising tendencies of experiments designed to achieve maximum output, and questioned the desirability of extreme specialisation from the point of view of the development of the individual. He suggested also that it was better to encourage individuals by lectures such as those of Professor Pear to take a pride in finding their own most efficient methods than to attempt to force upon them methods similarly deduced by the management.

General Meeting, December 2nd, 1919.

Professor F. E. Weiss, D.Sc., F.R.S., F.L.S. (*Deputy Chairman*), in the Chair.

Professor George Unwin, M.A. (Oxon.), Professor of Economic History in the Victoria University of Manchester, and 47, *Heaton Road, Withington, Manchester;* Mr. Alfred Ernest Steinthal, M.A., B.Sc., Treasurer of the Victoria University of Manchester, 19, *Ladybarn Road, Fallowfield, Manchester;* The Reverend F. G. Chevassût, M.A. (Cantab), F.R.A.S., Warden of St. Anselm's Hall, *St. Anselm's Hall, Victoria Park, Manchester;* The Reverend T. Nicklin, M.A., Warden of Hulme Hall, *Hulme Hall, Victoria Park, Manchester;* and Mr. A. E. Heath, M.A., Lecturer in Education in the Victoria University of Manchester, *The University, Manchester;* were elected Ordinary Members of the Socity.

Ordinary Meeting, December 2nd, 1919.

Professor F. E. Weiss, D.Sc., F.R.S., F.L.S. (*Deputy Chairman*), in the Chair.

Mr. C. L. Barnes, M.A., drew attention to the following book on the table :—"*Chemical Abstracts, Decennial Index Vols. 1-10 (1907-1916), Subject Index L-Z*," published by The American Chemical Society (8vo., Easton, Pa., 1919), purchased.

Mr. C. E. Stromeyer, M.Inst.C.E., M.Inst.M.E., explained a method by which roots of numbers can be easily and rapidly found by division sums. Let A^n be the number whose nth root is to be found, let G be a convenient number near to the probable value of A, then the approximate root is

$$R = G\frac{(n+1)\,A^n + (n-1)\,G^n}{(n+1)\,G^n + (n-1)\,A^n}$$

As it is desirable to know the accuracy of the result as measured by the approximate error $E = (A - R)$

$$E = \frac{n(R-G)\ (A^n + G^n) - (A^n - G^n)\ (R+G)}{n(A^n + G^n) - (A^n - G^n)}$$

The two denominators are the same.

Example. $\sqrt{2}$: Let $G = 1$. $R = \frac{7}{5} = 1{\cdot}4$.

Now let $G = 1{\cdot}4$. $R = 1{\cdot}4\ \frac{7{\cdot}96}{7{\cdot}88} = 1{\cdot}414214$.

Professor SYDNEY CHAPMAN, M.A., D.Sc., F.R.S., read a paper by Mr. L. V. MEADOWCROFT, B.A., M.Sc., entitled: "**A discussion of the theorems of Lambert and Adams on motion in elliptic and hyperbolic orbits.**"

This paper is printed in full in the *Memoirs.*

Mr. W. E. ALKINS, M.Sc., read a paper entitled "**Morphogenesis of** ***Reticularia lineata.***"

This paper is printed in full in the *Memoirs.*

General Meeting, December 16th, 1919.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

Dr. JOHN KERFOOT WOOD, F.C.S., F.I.C., Lecturer in Physical Chemistry in the College of Technology, Manchester, and 31, *Rowan Avenue, Brooklands, near Manchester;* Professor ARTHUR GEORGE GREEN, M.Sc., (Leeds), F.R.S., F.C.S., F.I.C., Research Chemist, *Holloway Clough, Arthog Road, Hale, Cheshire;* Mr. FRANK LASSEY, B.Sc., Manager of the Manchester Branch, British Fibro-cement Works, 414, *Corn Exchange Buildings, Manchester,* and *Northern Lea, Northenden Road, Sale, Cheshire;* Mr. WILLIS OPENSHAW HOWARTH, M.Sc. (Manc.), Lecturer in Botany in the Victoria University of Manchester, and *Fairlands,* 39, *Edge Lane, Chorlton-cum-Hardy, Manchester;* and Professor O. T. JONES, M.A. (Cantab.), D.Sc. (Wales), Professor of Geology in the Victoria University of Manchester, *The University, Manchester;* were elected Ordinary Members of the Society.

Ordinary Meeting, December 16th, 1919.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

Professor F. E. WEISS, D.Sc., F.R.S., F.L.S., exhibited and made a few remarks on a green jade charm made by natives of New Zealand.

Mr. W. J. Perry, B.A., read a paper entitled: "**The Historical Process.**"

The study of the geographical distribution of peoples in various stages of culture, and of the migrations of peoples, suggests that the degree of civilisation possessed by any community that has advanced beyond the pure hunting stage is the result, direct or indirect, of cultural influences propagated from some original centre. It seems as though the fundamental arts and crafts of civilisation were invented in one place, and that the knowledge of them was carried to the outlying parts of the earth, thus producing the various degrees of culture possessed by different communities. The study of archæological remains supports this contention.

If this conclusion be accepted, it becomes possible to regard the study of human society from a point of view different from that commonly adopted. We can examine the effects of various social institutions on behaviour. The hunting tribes, the most primitive men of whom we have direct knowledge, display a uniform type of behaviour: they are peaceful, truthful, monogamous, honest, kind to children and animals, and thus presumably represent the normal type of human behaviour. The people above them in culture have adopted the institutions of civilised peoples to varying degrees, and their modes of behaviour appear to correspond to their historical experience. The wide range of culture which exists in the world makes it possible to examine in detail the effects upon human beings of various social institutions, and thus to pave the way for the foundation of a Science of Society, the ultimate aim of which will be to determine which institutions are fitted to develop men to the greatest possible extent.

Mr. C. E. Stromeyer, M.Inst.C.E., M.Inst.M.E., read a paper on "**The Study of Nationalities,**" in which he pointed out that although structural peculiarities are very useful for differentiating non-related species they are of little use for the purpose of classifying branches of one species, and it is necessary to study their characteristics. He produced a paper which showed very clearly that there are very marked differences amongst the characteristics of different nationalities, for instance the semitic and slavonic races have wonderful memory gifts, and the Scandinavians are preeminently inventive. The author then dealt with the difficulties associated with the suggested study, pointing out that our words for the several characteristics have no very precise meanings, and he then dealt with the reagents which might be employed for revealing the fundamental characteristics of various nationalities.

General Meeting, January 6th, 1920.

Professor F. E. WEISS, D.Sc., F.R.S., F.L.S. (*Deputy Chairman*), in the Chair.

Mr. NORMAN S. HUBBARD, B.Sc., Metallurgical Research Department of the Broughton Copper Co., and 228, *Plymouth Grove, Manchester;* Mr. JOHN ALLAN, F.C.S., Technical Chemist, Chief Chemist at Messrs. Joseph Crossfield & Sons, Ltd., and 18, *Moorfield Road, West Didsbury, Manchester;* Mr. JAMES CHARLTON, Chemist, 40, *Lea Road, Heaton Moor, Stockport;* Miss MARJORIE DRURY, Secretary, Research Department, Messrs. Tootal Broadhurst Lee Co. Ltd., *c/o Messrs. Tootal Broadhurst Lee Co. Ltd.*, 56, *Oxford Street, Manchester;* and Miss AGNES CECILIA ALEXANDER, Physicist, Research Department, Messrs. Tootal Broadhurst Lee Co. Ltd., *c/o Messrs. Tootal Broadhurst Lee Co. Ltd.*, 56, *Oxford Street, Manchester;* were elected Ordinary Members of the Society.

Ordinary Meeting, January 6th, 1920.

Professor F. E. WEISS, D.Sc., F.R.S., F.L.S. (*Deputy Chairman*), in the Chair.

A vote of thanks was passed to the donors of the books upon the table.

Mr. R. W. JAMES, M.A., read a paper on "**The Antarctic: Shackleton's Expedition of 1914-17.**"

The aim of the expedition was to cross the Antarctic Continent. For this purpose, the main party was to establish a base as far south as possible in the Weddell Sea. From this base a sledging party was to cross the Continent, joining a supporting party from a second base established in the Ross Sea. The project could not be carried out, owing to bad ice conditions in the Weddell Sea preventing a landing. The "Endurance" was beset by ice in latitude 70° 30′ S., and after a nine months' drift was crushed and abandoned in latitude 69° 5′ S. on October 27, 1915. The crew formed a camp on the ice, which continued to drift north, and, 5½ months later, were able to take to the boats, ultimately reaching Elephant Island in the S. Shetland Group on April 15th, 1916. From Elephant Island, Sir Ernest Shackleton, with a party of five, made a remarkable boat-journey in a 22 ft. boat, reaching South Georgia, nearly 800 miles distant, in 16 days, and was able to obtain help, and relieve the Elephant Island party, all well, on August 30, 1916, after four attempts.

The peculiar conditions handicapped scientific work considerably, nevertheless some valuable results were obtained. Two hundred miles of new coast line were mapped; a chain of soundings was extended across the Weddell Sea; and much interesting work done on the natural history of sea-ice.

Slides illustrating the drift of the "Endurance," the formation and decay of the pack-ice, the crushing of the ship and the life on Elephant Island were shown.

General Meeting, January 20th, 1920.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

Mr. THOMAS HORNER, M.Sc.Tech. (Manc.), A.I.C., Chemist, 9, *Elm Bank, Humphrey Street, Crumpsall, Manchester;* Mr. SAMUEL KERSHAW, L.D.S., Dentist, 167, *Cheetham Hill Road, Manchester;* Miss DOROTHY GLADYS COWARD, M.Sc., Headmistress of the Broughton and Crumpsall High School, Manchester, *The Broughton and Crumpsall High School, Manchester;* and Mr. SYDNEY H. HIGGINS, M.Sc., Chief Research Chemist, The Bleachers' Association, Ltd., Manchester, *The Research Department, The Bleachers' Association, Ltd.*, 4, *Norfolk Street, Manchester;* were elected Ordinary Members of the Society.

Ordinary Meeting, January 20th, 1920.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

A vote of thanks was passed to the donors of the books on the table. These included *"Cheap Steam,"* vol. 3 (4to., London, 1919), presented by Messrs. Edward Bennis & Co., Ltd.

A valuable gift by Mr. HENRY BODDINGTON, J.P., of Pownall Hall, of a portrait of Henry D. Pochin, one time Mayor of Salford, in his chemical laboratory, was exhibited at the Meeting; and it was unanimously resolved that the best thanks of the Society be accorded to Mr. Boddington for his generous gift.

Professor W. M. CALDER, M.A., read a paper entitled **"Geography and History in the Mediterranean."**

Professor Calder described in detail the relation of the Mediterranean as a whole to the series of great plains lying to its north and south, and to the mountain systems known as the "roof of the world," running from the north of India to the Eastern Mediterranean, and reappearing in Greece, the Alps, the Pyrenees, and the Atlas mountains in the north of Africa.

After explaining how the main geographical features of the countries bordering the Mediterranean had influenced the development of their communications and trade and the growth of their states and institutions, Professor Calder showed that the group of routes entering the Mediterranean area came from the raw material producing districts in Central Asia and the Monsoon Countries, and down the valley of the Nile from Equatorial Africa. In the Mediterranean area these routes met the great roads passing into Northern and Western Europe. A great deal of ancient history coincides with the varying degrees of importance of these routes. In the eastern part of the

Mediterranean lay the greatest route in history, leading from the Persian Gulf to the Levant, generally called the Cilician Gates route. This route had western extensions which, passing through the body of Greece, had raised to importance the cities of Athens and Corinth, but which later, with the development of sea-craft, left Greece alone, and passed straight from the Levant to Italy and the West.

With the growth of European civilisation, the western extension of this route has swung round towards Western and Central Europe, and it has recently caused the world a considerable amount of trouble in the guise of the Berlin-Baghdad Railway. A railway running from Central Europe to the Persian Gulf is enormously important in itself, and its importance is increased by the vast areas which will one day be "tapped" by its extensions. Near Aleppo there already exists a railway junction whose political importance staggers the imagination, the junction of the future for London, Berlin, Calcutta, Cairo, and Cape Town. "Rail power" may one day restore the Levant to its ancient pride of place as the centre of communications of the Old World.

General Meeting, February 3rd, 1920.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

Mr. ALBERT ALFRED BUSS, F.R.A.S., Engineer, "*Barrowdale,*" 22, *Egerton Road, Chorlton-cum-Hardy, Manchester,* was elected an Ordinary Member of the Society.

Mr. CHARLES W. SUTTON, M.A. Chief Librarian of the Manchester Public Libraries, 323, *Great Clowes Street, Higher Broughton, Manchester;* Mr. WILLIAM SALVADOR CURPHEY, F.I.C., Chief Alkali Inspector, 87, *Canfield Gardens, Hampstead, London, N.W.6.;* and Mr. J. T. F. BISHOP, Retired Engineer, Honorary Secretary of the Manchester Chemical Club, 1890—1916, *Byways, Ayres End, Harpenden;* were elected Corresponding Members of the Society.

Ordinary Meeting, February 3rd, 1920.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

Professor EDMUND KNECHT, M.Sc.Tech., Ph.D., F.I.C., read a paper entitled **"Alpine Insolation Effects on Unprotected Wood."**

The author described a number of observations which he had made on the effect of direct sunshine on the wood of the Alpine log-huts or chalets, particularly in the vicinity of Villars sur

Ollon. A distinct change of colour in the exposed parts began after about 3 years after which a rich brown began to develop. This was followed after an average period of about 30 years by a blackening of the surface. When exposure had lasted a hundred years or more the whole of the exposed surface was sometimes charred or scorched to a uniform black, which presented under the microscope the appearance of coal, but the charring did not penetrate far below the surface. The fact that the sun's action was more marked on the western than on the eastern aspects appeared to indicate that the changes were brought about more by thermo-chemical than by photo-chemical action. The maximum temperature recorded by the black bulb thermometer in these Alpine altitudes was 66° C., which was very much below the temperature of decomposition at present generally accepted (130° C.). By prolonged heating of wood to 93° C. he had succeeded in producing not only browning but even incipient blackening of the surface. Further experiments in this direction were being undertaken but would require a long time for completion. The temperature of decomposition of wood appeared to have an important bearing on the question of coal formation. Incidentally the lecturer mentioned that bleached cotton was more or less profoundly altered by prolonged heating to a temperature considerably below the boiling point of water.

Mr. WILLIAM THOMSON, F.R.S.E., F.I.C., and Mr. HERBERT S. NEWMAN, M.Sc.Tech., read a paper entitled "**On the Behaviour of Amalgamated Aluminium and Aluminium Wire.**"

This paper is incorporated with that read on May 18th, 1920. (See *Proceedings*, 1919-20, p. xxiv.)

Mr. C. E. STROMEYER, Mem.Inst.C.E., M.Inst.M.E., read a paper entitled "**The After Effects of Cannibalism.**"

The author explained that cannibalism would not be indulged in by people with vegetarian tastes nor by people who, having a craving for animal food, could satisfy it, as was the case with the North American Indians and the North Europeans. Others who had this craving but who had no animals to eat, for instance the Fiji Islanders whose largest animals were one rat and five types of bat, would become cannibals. But no state in which indiscriminate man-eating was indulged in could have flourished unless cannibalism was controlled. Officials had therefore to be appointed, and these would invent rites and ceremonies for the protection of their craft. These ceremonies would after a time become religious rites.

This state had been reached in Mexico when the Spaniards arrived; it seems also to have been reached in the Mesopotamian

Empires when domesticated animals were first introduced amongst them. Human sacrifices were to a certain extent discontinued, but the rites were continued. The religious animal sacrifices of the ancients were therefore an after effect of human sacrifices. Even our practice of saying grace before meat and not before drink, though water coming from the skies is more of the nature of a heavenly gift than the meat of animals which have to be killed, may possibly be one of the after effects of cannibalism of 4,000 years ago.

General Meeting, February 17th, 1920.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

Dr. W. J. WALKER, B.Sc. (St. Andrew's), A.M.Inst.C.E., Lecturer in Mechanical Engineering in the College of Technology, Manchester *Arbroath, Westcourt Road, Ashton-on-Mersey,* was elected an Ordinary Member of the Society.

Ordinary Meeting, February 17th, 1920.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

A vote of thanks was passed to the donors of the books on the table.

Dr. T. GRAHAM BROWN read a paper entitled **"The Functions of the Brain."**

The activity of an animal, as seen by an observer, consists in movements of its limbs, changes of its attitude, changes in its expression (movements of the face and of the hair, etc.), and so on. This activity is usually called the " behaviour " of the animal. *In itself* the action of the animal is a physiological one. It may be analysed and described in terms of physiological mechanism. But it is also used as an *index* of the mental processes of the animal. These two manners in which behaviour may be examined—as a thing in itself and as an index of another sort of phenomenon—are not mutually antagonistic. They are complementary, and the facts found by either of them may assist research in the other.

The separate movements of the parts of the body are *integrated* by the nervous system in the total behaviour. This integration may occur at different levels in the central nervous system. At the lowest level—the " spinal level "—the integration is a comparatively simple one. At an intermediate level the integration is a more complex one. The great brain must be present if the animal is to exhibit all the finer shades of behaviour which characterise the normal animal.

There are two general methods of examination which are used in the investigation of the brain. Of these the first is that of experimental removal of a part of it, and the observation of any subsequent change in the animal's behaviour. The second method is that of stimulation whilst the animal is under the influence of a narcotic. The movements then brought about are studied. The two methods were illustrated by experimental observations; particularly by observations on the physiology of the cortex of the great brain.

When the great brain has been injured by experiment, *paralysis* of a function often occurs. This is seen, for instance, in the paralysis of a limb. A similar state occurs in man after disease of the proper part of the cortex of the brain. A fact of interest in this paralysis is its rapid disappearance in animals. The recovery is not so often seen in the case of disease of the human brain.

These observations on the brain have led to a theory of "cerebral localisation of function" which in its present form is open to criticism. It looks as if the cortex of the great brain is not so essentially necessary to many of these functions as was formerly supposed. It is perhaps possible that a more or less complete mechanism of behaviour is present in lower levels of the nervous system, and that the cerebral cortex is the place where the most complex stimuli (sound, taste, smell, vision, etc.) are compounded together. Their resultant then can affect the lower centres which actually condition the behaviour. The activity of the cortex would then be regarded as one which *directed* the behaviour.

Ordinary Meeting, March 2nd, 1920.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

A vote of thanks was passed to the donors of the books on the table. The Society now subscribes to *Discovery* and *The Journal of Industrial and Engineering Chemistry.*

The PRESIDENT referred sympathetically to the death, on February 27th, of Mr. HERMANN WOOLLEY, who was elected an ordinary Member of the Society in 1918.

Mr. C. L. BARNES, M.A., made a short communication relating to "Einstein's Theory of Space and Time"; and The PRESIDENT and Mr. C. E. STROMEYER took part in the discussion.

Reference was made to a letter in *Nature* of February 12th, 1920, in which the space between the principal focus of a convex mirror and the mirror itself was contrasted with the space outside. If the reflected images of human beings in such a mirror were endowed with intelligence, volition, the ability to measure lines, areas, and so forth, the principal focus, to them, would be at infinity. Equal straight lines, as measured outwards in the direction of a radius would have images of progressively diminishing length in the direction of the focus, but the phantoms would be unaware of this, as their measuring instruments would contract in the same ratio. Other consequences of the distortion were pointed out, and their bearing on Einstein's theory alluded to.

Reference was also made by Mr. C. L. BARNES to the death of Dr. C. GORDON HEWITT, Dominion Entomologist, Canada; a former Member of the Society, well known for his researches on the House Fly, the diseases of trees, &c. The PRESIDENT and Professor Sir WILLIAM BOYD DAWKINS also referred to Dr. Gordon Hewitt and his work.

Mr. W. J. PERRY, B.A., read a paper entitled **"The Search for Gold and Pearls in Neolithic Times."**

Further research on the distributions of early sites of civilisation and of the sources of gold and pearls has produced a mass of evidence to substantiate and enlarge the thesis of a communication to the Manchester Literary and Philosophical Society in 1915 on "The Relationship between the Geographical Distribution of Megalithic Monuments and Ancient Mines." The evidence now suggests that not only megalithic monuments but early sites in general marked the settlements of seekers after gold and pearls; amber and purple having also played their part in attracting strangers. These settlements are mostly localised in the basins of rivers containing gold or pearl-bearing mussels, and the distribution map shows that the early seekers for these objects did not allow much to escape them.

Further inquiry will be necessary in order to determine the precise age when this search began.

Ordinary Meeting, March 16th, 1920.

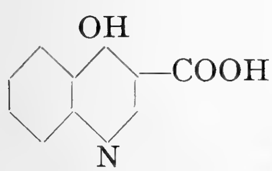
Mr. WILLIAM THOMSON, F.R.S.E., F.I.C. (*Vice-President*), in the Chair.

A vote of thanks was passed to the donors of the books upon the table. These included "*Oeuvres Completes de Thomas Jan Stieltjes*" (4to, Groningen, 1918), presented by the Société Mathématique, Amsterdam.

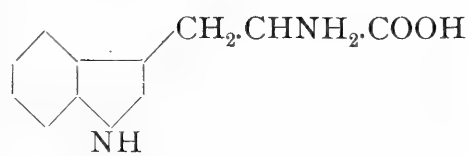
Mr. J. WILFRID JACKSON, F.G.S., and Dr. R. S. WILLOWS, M.A., were nominated Auditors of the Society's Accounts for the session 1919—1920.

Professor ROBERT ROBINSON, D.Sc., F.R.S., read a **"Note on the Mechanism of the Production of Kynurenic Acid in the Dog."**

Kynurenic acid was discovered in the urine of dogs by J. von Liebig in 1853 (*Ann.*, **86**, 125), and was identified by R. Camps (*Ber.*, 1901, **34**, 2707) with a synthetically prepared 4-hydroxy-quinoline—3-carboxylic acid (I) melting at 266—267°C. A. Ellinger (*Ber.*, 1904, **37**, 1801) discovered that the administration of tryptophane (II) to dogs and rabbits resulted in an increased production of the acid and was led to postulate a relation between the two substances, which his further work soon proved to be erroneous. A. Homer (*J. Biol. Chem.*, 1914, **17**, 509—518) definitely proved that kynurenic acid melts at 288—289°, and identified the acid with 4-hydroxyquinoline-2-carboxylic acid (III), which substance, curiously enough, had also been prepared by Camps (*Ber.*, 1901, **34**, 2712) by the action of aqueous alcoholic sodium hydroxide on the product of condensation of o-aminoacetophenone and ethyl oxalate at 150—160°C.



I.



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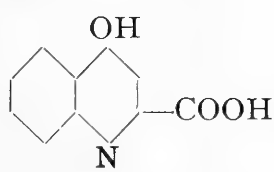
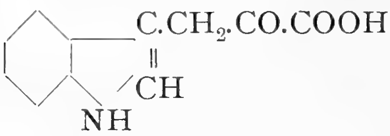


III.

Homer (*J. Biol. Chem.*, 1915, **22**, 391—405) considered that the relation between tryptophane and kynurenic acid might not be direct in the sense that the latter substance is actually derived from the former, but that the metabolic processes induced by the tryptophane might involve the synthesis of kynurenic acid in side reactions. This conclusion was reached partly as the result of an experimental study in which it was shown that the ratio between the tryptophane ingested and kynurenic acid excreted was not a simple one, but depended on the age and condition of the animal and partly because the transformation would involve the enlargement of a five-membered ring. It appears to the present author that the conversion of tryptophane into kynurenic acid is susceptible of a simple explanation, and that the process is primarily one of oxidation. The first product might well be the keto-acid (IV) which then suffers further oxidation resulting in the fission of the indole ring and the formation of the compound V.



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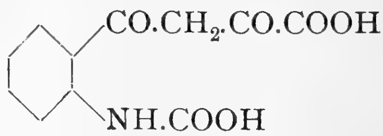
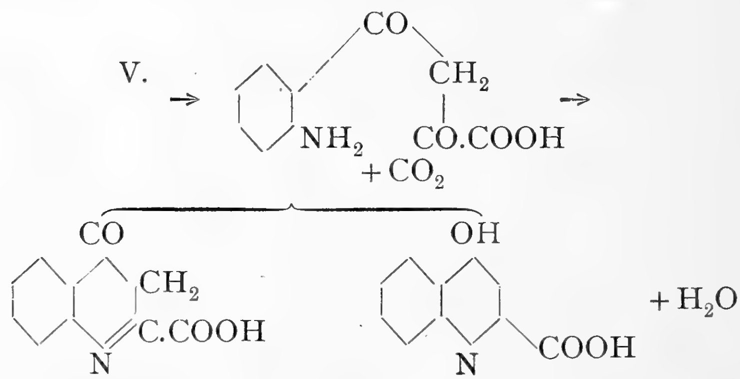


V.

This hypothetical intermediate, if produced in the laboratory, would beyond doubt be found to yield kynurenic acid when treated with weak alkalies. The necessary changes being hydrolysis of the unstable carbamic acid grouping and closure of the quinoline ring by the aid of one of those reactions which are known to proceed with the greatest facililty, indeed, in many cases, spontaneously. The process is illustrated below.



keto form. *enol form.*

The foregoing suggestion was made by the author in a letter to Professor George Barger, F.R S., in December 1919, and in February of this year Dr. Barger has informed me that Ellinger has succeeded in preparing the keto-acid (IV) and finds that when this is given to dogs the kynurenic acid formation is increased. This result strongly supports the view which is expressed above.

A paper by Professor ARTHUR LAPWORTH, D.Sc., F.R.S., entitled "**Latent polarities of Atoms and Mechanism of Reaction, with Special Reference to Carbonyl Compounds.**" was, in the author's absence, read by Professor Robert Robinson.

Professor ROBERT ROBINSON, D.Sc., F.R.S., then read a paper entitled "**The Conjugation of Partial Valencies.**"

These two papers are printed in full in the *Memoirs*.

Annual General Meeting, April 20th, 1920.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

Mr. REGINALD FELIX GWYTHER, M.A., Honorary Secretary of the Society, 1888—1897, *Hallcroft, Dufton, Westmorland*, was elected a Corresponding Member of the Society.

Mr. ROBERT ARNOLD WARDLE, M.Sc., Lecturer in Economic Zoology in the Victoria University of Manchester, 7, *Hilton Crescent, Hilton Park, Prestwich, Manchester;* Mr. HUBERT JOHN PATRIDGE VENN, B.Sc. (Lond.), A.I.C., Research Chemist, Messrs. Tootal Broadhurst Lee Co. Ltd., *c/o Messrs. Tootal Broadhurst Lee Co. Ltd.*, 56, *Oxford Street, Manchester*, and *Sunny Bank, Hill Lane, Blackley, Manchester;* Mr. FRANK HERBERT PARKER, B.Sc. (London), Research Physicist, Messrs. Tootal Broadhurst Lee Co. Ltd., 33, *Stanley Road, Whalley Range, Manchester;* Miss DOROTHY ASHTON, B.Sc., A.I.C., Works Chemist, 18, *Randlesham Street, Heaton Park, Manchester;* Miss MARION CHADWICK, M.Sc.Tech., University Demonstrator in Applied Chemistry, *Ingleside, Didsbury Road, Stockport;* Mr. CHARLES CARTWRIGHT, M.A., Accountant, *Pannal, Brooklands Road, Higher Crumpsall, Manchester;* Mr. WILLIAM ERNEST ALKINS, M.Sc., Assistant Lecturer in Metallurgy in the Victoria University of Manchester, *Stoneydale, Ookamoor, Stoke-on-Trent;* and Mr. HAROLD SUTCLIFFE, Assistant Manager, *Kkovah Works, Old Trafford, Manchester;* were elected Ordinary Members of the Society.

The Annual Report of the Council and the Statement of Accounts were presented, and it was resolved :—That the Annual Report, together with the Statement of Accounts, be adopted, and that they be printed in the Society's *Proceedings*.

Miss MARJORIE DRURY and Mr. J. WILFRID JACKSON, F.G.S., were appointed Scrutineers of the balloting papers.

The following Members were elected Officers of the Society and Members of the Council for the ensuing year :—

President : Sir HENRY A. MIERS, M.A., D.Sc., F.R.S.

Vice-Presidents : FRANCIS JONES, M.Sc., F.R.S.E., F.C.S.; R. L. TAYLOR, F.C.S., F.I.C.; WILLIAM THOMSON, F.R.S.E., F.I.C.; R. H. CLAYTON, B.Sc.

Secretaries : H. F. COWARD, D.Sc., F.I.C.; C. A. EDWARDS, D.Sc.

Treasurer : W. HENRY TODD.

Librarian : C. L. BARNES, M.A.

Curator : W. W. HALDANE GEE, B.Sc., M.Sc.Tech., A.M.I.E.E.

Other Members of the Council : FRANCIS NICHOLSON, F.Z.S.; ARTHUR LAPWORTH, D.Sc., F.R.S., F.I.C.; KENNETH LEE, LL.D.; C. E. STROMEYER, O.B.E., M.Inst.C.E., M.Inst.Mech.E.; W. M. TATTERSALL, D.Sc.; LEONARD E. VLIES, F.C.S., F.I.C.; F. W. ATACK, M.Sc.Tech., B.Sc., F.I.C.; T. H. PEAR, M.A., B.Sc.; WILFRID ROBINSON, D.Sc.

Ordinary Meeting, April 20th, 1920.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

A vote of thanks was passed to the donors of the books upon the table.

Mr. W. J. PERRY, B.A., read a paper entitled:—**"The Origin of Warlike States."**

In a previous communication to this Society, and elsewhere ("An Ethnological Study of Warfare," *Mem. Manchr. Lit. and Phil. Soc.,* Vol. 61, 1917; "War and Civilisation," Lecture at Rylands Library, Sept. 13th, 1918: The "Megalithic Culture of Indonesia," Manchester, 1918), the theory has been put forward that, speaking generally, warlike states are those with a hereditary military aristocracy. An examination of the ruling groups of the chief historical peoples, Teutonic, Turko-Tartar, Semitic, does not give any signs of their origin in a simpler form of society. The facts suggest their beginning as small groups claiming divine descent. These groups seem to have sprung from the ruling families of a former stage of society which is well known, that called "matriarchal," in which descent in social groups, inheritance to property, succession to rank, went through women, and the chief feature of religion was the cult of the Great Mother. Just after the new groups of rulers had been formed, the institutions had become patrilineal, and the Great Mother was replaced by gods.

The practice of Heraldry is widespread among ruling classes in all parts of the earth, and the study of it gives results which go to verify the theory which comes out of the study of ruling groups; namely, that, all over the world, dynasties have sprung from former ruling classes, and have not sprung up spontaneously in various places. This law of "dynastic continuity," if true, leads to the conclusion that all ruling classes in the world are derived from one original group. This result is in harmony with the claim of Professor Elliot Smith, that all civilisation originated in the Egypto-Sumerian region.

General Meeting, May 4th, 1920.

Mr. WILLIAM THOMSON, F.R.S.E., F.I.C. (*Vice-President*), in the Chair.

Dr. JEAN J. BLOCH, Pharmaceutical Chemist, Manager of the Hollinwood Chemical Co. Ltd., Hollinwood, 400, *Manchester Road, Hollinwood;* Mr. WILLIAM SMALLEY, Engineer, *Springfield, Castleton, near Manchester;* Mr. FRANK WILLIAM BAILEY, Wood Pulp Mill Manager and Chemist, *Lee Mount, Glossop, Derbyshire;* Mr. FRANK BAMFORD, B.Sc., (Lond.), Chemist, British Dyestuffs Corporation (Huddersfield) Ltd., 42, *The Square, Fairfield, Manchester;* Dr. ARTHUR ERNEST OXLEY, M.A. (Cantab.), Head of Physical Department, British Cotton Industry Research Association, *c/o British Cotton Industry Research Association, Shirley Institute, Didsbury, Manchester;* Dr. JOHN CHARLES WITHERS, A.I.C., Chemist, British Cotton Industry Research Association, *c/o British Cotton Industry Research Association, Shirley Institute, Didsbury, Manchester;* and Dr. ARTHUR WILLIAM CROSSLEY, C.M.G., C.B.E., D.Sc. (Manc.), LL.D. (St. Andrews), Ph.D. (Würz.), F.R.S., Director British Cotton Industry Research Association, *c/o British Cotton Industry Research Association, Shirley Institute, Didsbury, Manchester;* were elected Ordinary Members of the Society.

Ordinary Meeting, May 4th, 1920.

Mr. WILLIAM THOMSON, F.R.S.E., F.I.C. (*Vice-President*), in the Chair.

A vote of thanks was passed to the donors of the books upon the table. These included "*Slavic Europe, A Bibliography . . .*" by R. J. Kerner (8vo., Cambridge, Mass., U.S.A.), presented by the Harvard College Library.

Mr. W. J. PERRY, B.A., read for Major THOMAS CHERRY, A.A.M.C., M.D., M.S., a paper entitled :—"**The Origin of Agriculture.**"

The author showed that the annual flood cycle of the Nile provided perfect conditions for the growth of cereals. Since none other of the great rivers on the banks of which civilisation first appeared affords such natural possibilities for the growth of cereals, it was claimed that man must have learned in Egypt the lesson which the Nile was trying to teach him, that of irrigation and the cultivation of cereals.

The author also discussed the origins of wheat and barley. He claimed that the originals of our cultivated barley probably evolved in the valley of the Nile, while those of our cultivated wheats probably evolved on one of the islands of the Aegean Archipelago.

General Meeting, May 18th, 1920.

Mr. R. L. TAYLOR, F.C.S., F.I.C. (*Vice-President*), in the Chair.

Dr. ALBERT FRANK STANLEY KENT, M.A., Director of the Department of Industrial Administration, The College of Technology, Manchester, *The College of Technology, Manchester;* Mrs. ELIZABETH C. AGAR, 16, *Elm Road, Didsbury, Manchester;* and THOMAS G. RUSSELL, Solicitor, *King Street, Manchester,* and *The Cottage, Lees Road, Bramhall, Cheshire;* were elected Ordinary Members of the Society.

Ordinary Meeting, May 18th, 1920.

Mr. R. L. TAYLOR, F.C.S., F.I.C. (*Vice-President*), in the Chair.

A vote of thanks was passed to the donors of the books upon the table.

Dr. R. S. WILLOWS, M.A., exhibited and described a lantern slide giving a transverse section of cotton fibre, magnified 20,000 times, showing Ball's daily growth rings.

Mr. WILLIAM THOMSON, F.R.S.E., F.C.S., F.I.C., read the following paper by himself and Mr. HERBERT S. NEWMAN, M.Sc.Tech., containing further notes on their communication read before the Society on February 3rd, 1920.

"On the Behaviour of Amalgamated Aluminium and Aluminium Wire."

When aluminium wire (that used by us was $^{15}/_{1000}$th of an inch in diameter) is brought into contact with mercury there at once begins to grow from the wire a fine feathery substance which may extend in an hour or two to as much as half an inch or more; this substance is hydrated aluminium oxide (alumina) associated with a small quantity of mercury in the free state.

This observation has been made frequently by others; although we find scanty record of it, and none in the indices of the Scientific Journals to which we had access. Carl Jehn and H. Hinze (*Ber.*, **7**, 1498), on the 11th November, 1874, refer, in a note of a few lines, to aluminium as combining with mercury and forming these curious growths. According to them, after the piece of aluminium had been rubbed with wash leather which had been in contact with mercury, the rubbed surface became warm and dull; and almost instantaneously white tufts began to grow from it to a final length of 3 cm. "These proved to be Al_2O_3."

A reference is made to it in No. 15 of "The Model Engineer Series," Third Edition, page 56, which is a work written to provide "Scientific Amusement." In this the author, Aurel de Ratti, says this phenomenon was discovered by him accidentally in 1895. The aluminium he used was obtained by breaking off a piece from an aluminium pen-holder, in order to obtain a clean and rugged edge without which the experiment would not succeed. He thoroughly moistened the piece and then dipped it into mercury: in a minute or two afterwards small white spots appeared on the sharpest corners and these rapidly grew till they appeared like feathery growths about an inch long.

In his work entitled "The Evolution of Matter," Third English Edition (1907), p. 405, Dr. Gustave Le Bon speaks of "The Transformation of the properties of Aluminium" by its amalgamation with mercury. He observed that the temperature during oxidation rose to 102° C., that it was the hydrated oxide of aluminium which was formed, that this oxidation took place only in damp air or oxygen, and that an exceedingly minute quantity of mercury effected the complete oxidation of the aluminium. He mentions that he could find no reference to the properties given to aluminium by mercury in any of the most accredited treatises; he consulted the eminent chemist M. Ditte, Professor of Chemistry at the Sorbonne, the author of the most complete and recent work on the properties of aluminium, but he knew nothing of the facts Le Bon had pointed out, who therefore assumed that he was the first to publish anything about it.

We found that for these growths to take place both oxygen and moisture must be present simultaneously. Thus, they will not grow in damp hydrogen or carbon dioxide, nor will they grow in air which has been dried by passage through concentrated sulphuric acid, nor at an elevated temperature of—say—75° C. In damp air containing ether vapour the growths are restricted. They are not formed at all in chlorine gas; and a trace of hydrochloric acid or of ammonia in damp air prevents the growths. Much heat is evolved during the development of the growths. We found the best results to be obtained by amalgamating the aluminium with Nessler's solution, which is an alkaline solution of mercuric chloride in potassium iodide. In such a case 100 parts by weight of wire gave a growth weighing 93.91 parts, the wire left weighing 67.76 parts, so that 32.24 parts of aluminium had become oxidised into alumina, whilst the mercury left in the 67.76 parts of wire amounted to 0.62 part. A neutral solution of mercuric chloride answers this purpose; but the growths are not so profuse as when an alkaline solution is used. If, after passing through the mercuric solution the wire be then passed through a drop of metallic mercury, a still better growth is obtained.

It was observed that the growth never takes place over the whole surface of the wire; but tends to concentrate itself along one side or sometimes two sides of the amalgamated wire when this is lying on a flat surface; whilst in the case of an amalgamated wire suspended freely or fixed upright, 3 lines of growth at angles of 120° from each frequently develop.

When an amalgamated wire is placed for two hours in dry air the mercury originally present on the surface presumably sinks into the aluminium and when the wire is afterwards exposed to damp air no growth takes place.

When aluminium foil is amalgamated and put in water it rapidly becomes converted into the hydrated oxide, which sometimes assumes a laminated structure exhibiting an iridescent effect resembling Mother-of-Pearl. When this oxide dries it becomes dull white and loses its iridescence.

When exposed to air, amalgamated aluminium foil gives rise to growths; but these seldom assume fine feathery shapes unless the degree of the humidity of the air be suitable. They usually occur as very copious dense growths; and a striking effect is obtained by writing on aluminium foil with Nessler's solution and allowing the growth to develop; when it finally forms white tufts along the lines of the letters.

It is very remarkable that no such growths could be obtained from amalgamated magnesium although this metal undergoes oxidation more readily than aluminium at the ordinary temperature of the air.

"**Further Notes on Aluminium Amalgam.**" 18th May, 1920, by the same authors.

On the 3rd of February last we showed examples of the delicate white filaments which grew out from aluminium wire which had previously been rubbed with metallic mercury or otherwise amalgamated.

These filaments we found to contain mercury and we determined the quantity present in some of the growths from wires amalgamated in different ways.

With a view to find whether the mercury associated with the alumina which constituted these growths was a definite quantity relative to the alumina, we submitted them to analysis and herewith we give the composition of the growths in six different experiments.

PERCENTAGE.

Composition of Filamentous Growths from Aluminium Wire Amalgamated with Nessler's Solution from which the excess of Mercury and liquor was :—

		Wiped off with a cloth. *a.*	Wiped off with a cloth. *b.*	Wiped off and the wire then passed through dry mercury.			Not wiped, but washed with alcohol and then with ether.
Mercury		4.55	4.54				20.21
Hygroscopic water (dried over strong sulphuric acid) ...	5.14			70.8	67.5	75.4	
Water (lost at 100°C.)	16.17	30.71	31.82				*61.30
,, (,, red heat)	9.40						
Alumina (Al_2O_3) ...		64.74	63.64	29.2	32.5	24.6	18.49
		100.00	100.00	100.0	100.0	100.0	100.00

* The cooling effect of the ether treatment probably had the effect of condensing an excessive quantity of water on to the wire.

These results show that the alumina growths formed by the presence of mercury on aluminium appeared to carry with them mechanically a quantity of mercury depending on the amount present in excess upon the surface; and that they do not form at all unless such excess exists on the surface.

With a moderate excess the growth is pure white, with a large excess it appears grey, and the quantity of mercury associated with the alumina formed depends on the excess present.

The method of growth appears to be somewhat erratic but in several cases quite interesting. In one experiment we made by incorporating the amalgamated wire with a drop of mercury which had afterwards a perfectly smooth surface, a growth appeared over the whole of the top surface and none on the sides; this growth increased but gradually ceased around the periphery, the central growth continuing till it appeared as a truly-formed inverted cone supported on its apex on the drop of mercury.

On repeating this experiment several times the growths appeared as a profusion of filaments completely covering the globule of mercury and extending for half an inch around it.

Neither pure damp oxygen nor ozone had any effect in accelerating or adding to the profusion of the growths.

The study of the action of mercury on aluminium is extremely interesting as regards the character of this metal; if aluminium be put in water no action is observed, but when amalgamated it immediately decomposes the water liberating hydrogen; when zinc is amalgamated, the mercury tends to resist the action of the water on the zinc and this is still more marked when the amalgamated zinc is immersed in weak acid. Under these conditions it resists the action of the acid but if immersed in its unamalgamated condition the weak acid attacks it at once.

Professor SYDNEY CHAPMAN, M.A., D.Sc., F.R.S., made a few remarks on **"The Lunar Tide in the Earth's Atmosphere,"** in which he pointed out that the atmosphere, like the oceans and the solid earth, is subject to the tidal influences of the sun and the moon. The barometric pressure shows a very minute tidal variation with the period of half a lunar day, this variation being determined only by a difficult process of averaging-out other regular and irregular variations from long series of hourly barometric observations, so that data from very few stations are available. Many questions suggested by the data remain unanswered, but as further data become available, and the theory of atmospheric tides is extended, our knowledge of our atmosphere may become of very great importance.

PROCEEDINGS

OF

THE MANCHESTER LITERARY AND

PHILOSOPHICAL SOCIETY

CHEMICAL SECTION.

Ordinary Meeting, October 24th, 1919.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S., Vice-Chancellor of the Victoria University of Manchester, in the Chair.

At the Opening Meeting of the newly formed CHEMICAL SECTION of the Society, Professor Sir WILLIAM J. POPE, M.A., D.Sc., LL.D., F.R.S., Professor of Chemistry in the University of Cambridge, gave an Address on **"The Photography of Coloured Objects."**

The ordinary photographic plate is sensitive only to blue and violet light and not to red or yellow. The plate thus receives much the same impression of a parti-coloured scene focussed upon it as we should receive on viewing the scene through deep blue spectacles. The lively discussions concerning the claims of photography as an artistic medium which were fashionable some twenty years ago centred in reality about this limitation of sensitiveness of the ordinary photographic plate; no method of pictorial reproduction which rendered the yellow narcissus and the bright red General McArthur rose as black, whilst showing the violet as white, can be described as artistic. The prime requisite of any photographic process for the representation of parti-coloured objects is obviously that the photographic plate used should be sensitive to light other than the blue and violet; given a plate which is acted upon by light from any part of the visual spectrum many devices become applicable for the production of a satisfactory presentment in monochrome of the coloured object or for the reproduction of the actual component colours.

The first truly scientific appreciation of this principle was stated by Clerk Maxwell, the first Cavendish Professor in the University of Cambridge, who in 1861 exhibited three photographs of a tartan ribbon taken through red, green and blue colour-filters respectively, and pointed out that the component colours could be reproduced by superposing the three images, each illuminated by appropriately coloured light. Maxwell remarked that "by finding photographic materials more sensitive to less refrangible rays the representation of the colours of objects might be greatly improved." Long after Maxwell's day it was discovered that the ordinary photographic plate can be rendered sensitive to green, yellow and red light by incorporating certain dyestuffs with the material of the sensitive film; previous to the war all the various methods of colour photography—the first of which was devised by Professor Joly, of Dublin—the modern processes of photographic colour-printing, and the present-day panchromatic photographic methods for obtaining a correct rendering in monochrome of parti-coloured objects, were based upon the success which had been attained in imparting sensitiveness throughout the visual spectrum to the ordinary blue-sensitive photographic plate. By staining the plate with erythrosine it becomes sensitive to green and orange; plates so treated are termed orthochromatic. A number of dyestuffs belonging to the class of cyanine dyes discovered by Greville Williams, in 1856, are capable, however, of sensitising a photographic plate throughout the whole range of the visible spectrum. These substances are difficult to make and but little concerning their preparation and chemical behaviour has been published; their photographic applications were carefully studied by several of the large German coal-tar colour firms, and those most suitable for use in colour photography were selected and put on the market under trade names which disguised their chemical identity. At the outbreak of war the Allies were entirely dependent on Germany for these so-called photographic sensitisers; such substances had never been made in this country and but little information as to the identity of the chief sensitisers and their methods of preparation was available. A little acquaintance with scientific photography suffices to show that this situation not only affects such æsthetic industries as those of artistic photography and colour-printing but is also vital to aeroplane photography.

Thus, a distant scene in bright sunlight is always seen to be obscured by a slight haze; this haze is enormously intensified when the scene is photographed on an ordinary blue-sensitive plate, intensified to such an extent that the photographic reproduction of the haze may blot out the whole distant view. The reason for this is that a clear atmosphere is less penetrable by blue light than by light from the less refrangible end of the spectrum. The blue-sensitive plate cannot see far into the distance because of the comparative opacity of the clear atmosphere to blue light; the eye sees further because it is more sensitive to red than to blue. Obviously, if a distant scene could be photographed in red light only, the picture would reveal much more detail because of the cutting off of the haze owing to the greater penetrating power possessed by red light in a clear atmosphere.

With these considerations in mind the experimental investigation of sensitising dyestuffs was instituted in the chemical laboratories of the University of Cambridge by Dr. W. H. Mills and myself at the end of 1914. Methods for producing the ordinary sensitising dyestuffs on a technical scale were devised, and all the sensitisers used by the Allies have been prepared in the Cambridge laboratories since the German importation ceased. Our photographic air-service was non-existent at the outbreak of war; it was slowly built up until it ultimately became of great magnitude and attained a high efficiency. It started by using ordinary blue-sensitive plates, but at the date of the Armistice some 80 per cent. of the plates used were red-sensitive or pan-chromatic plates.

The best panchromatic plate made in pre-war days possessed about one-third the sensitiveness to red as to blue light. At the present time a very rapid panchromatic plate is on the market which is much faster to red than to blue light; the rapidity of the plate to red light has been thus increased about four-fold. The advantages to be gained by the skilful use of the present highly-perfected panchromatised plates in our photographic air service, in the circumvention of camouflage colour schemes, and in the photography of distant scenes in spectroscopically pure light, are among the most important studies of the new service. The peace applications of panchromatic plates will undoubtedly multiply rapidly. A number of lantern slides were shown illustrating the points referred to above.

The chief processes at present available for the photographic reproduction of the colours of parti-coloured objects were then explained and examples of each were exhibited.

General Meeting, November 28th, 1919.

Mr. R. H. CLAYTON, B.Sc., in the Chair.

It was resolved that the Officers of the Chemical Section be as follows :—R. H. CLAYTON, B.Sc. (*Chairman*); J. H. LESTER, M.Sc., F.I.C. (*Hon. Treasurer*); F. W. ATACK, M.Sc.Tech., B.Sc. (*Hon. Secretary*); and the Members of the Committee :—

Edward Ardern, D.Sc., F.I.C.; H. J. Bailey; Percy Bean, F.C.S.; W. H. Bentley, D.Sc., F.C.S.; Joseph Brewerton; David Cardwell, M.Sc., F.I.C.; H. F. Coward, D.Sc., F.I.C.; J. B. Cullen; R. B. Forster, D.Sc.; W. B. Hart, F.C.S., F.I.C.; H. G. A. Hickling, D.Sc., F.G.S.; Francis Jones, M.Sc., F.R.S.E., F.C.S.; Arthur Lapworth, D.Sc., F.R.S., F.I.C.; T. G. Marsh; S. E. Melling, F.C.S., F.I.C.; F. Lee Pyman, D.Sc., Ph.D.; L Guy Radcliffe, M.Sc.Tech., F.I.C.; Rona Robinson, M.Sc., A.I.C.; W. Scott Taggart, M.I.Mech.E.; Leonard E. Vlies, F.C.S., F.I.C.; J. A. Weil, and T. Roland Wollaston, M.I.Mech.E.

It was decided that the Officers and the members of the Committee should be disbanded in March next, and that the present Committee should draw up the Constitution and Rules of the Chemical Section for submission to the Council.

It was agreed that all members of the Society should be entitled to attend meetings of the Chemical Section and should receive notices, but any member of the Society desiring to be a member of the Chemical Section should give his name to the Hon. Secretary of the Section.

Ordinary Meeting, November 28th, 1919.

Mr. R. H. CLAYTON, B.Sc. (*Chairman*), in the Chair.

Mr. R. H. Clayton opened a debate on "**The Future of the Chemical Section**;" and he outlined the scheme for the extension of the Society's house to provide further accommodation.

Ordinary Meeting, December 18th, 1919.

Mr. H. N. MORRIS in the Chair.

Mr. HAROLD MOORE, M.Sc.Tech., A.I.C., opened a debate on "**Future Supplies of Motor Fuel.**"

Mr. Moore said:—"In dealing with such a many-sided and highly technical subject as the future supply of motor fuel, it is only possible to give a brief outline of the subject in the time available this evening. I therefore propose to limit myself to giving a rough sketch of the present position.

Until the advent of the internal combustion engine burning liquid fuels the lighter petroleum products were almost waste products, and were used for heating stills, boilers, etc., and in some cases were even allowed to evaporate away. The actual separation of these volatile products was necessary on account of the flash point regulations dealing with the storage and transport of the heavier petroleum products.

The demand for petrol for automobile engines was therefore readily met in the early days of the petrol engine, though it was necessary to subject the volatile products to the acid and alkali washes known as the refining process. The specific gravity of motor spirit in 1905 was about .690 at 15° C., and it was a highly volatile product. To-day some grades of "spirit" have specific gravities as high as .760.

The import of petrol into this country in 1905 was 18,000,000 gallons, and in 1914, 120,000,000 gallons. The increased demand has been met in the first place by extending the limits of the "cut" for the petrol fractions to include higher boiling fractions. As this produced heavier spirit, and the engines of that day were only capable of utilising highly volatile fractions, the demand would have exceeded the supply if the invention of the jet carburettor had not saved the situation by allowing the use of heavier spirit, and of spirit collected over wider ranges of temperature. Following this development the temperature ranges of the "cut" in the distillation were increased to include both heavier and lighter products, and of recent years the heavier constituents of natural gas have been condensed by pressure and cooling and used as a "livening" agent.

These developments would have been insufficient to cope with the increasing demand for spirit had it not been for the introduction of cracking on a large scale. Cracking consists of subjecting heavy petroleum oils (usually of higher boiling point than kerosene) to heat and pressure, whereby compounds of lower molecular weight, and therefore lower boiling point are produced. Cracked spirit is of higher gravity than "straight" distilled spirit of the same boiling point. It is slightly disagreeable as regards smell, but otherwise a good fuel. Nearly all of the cracked spirit produced in the United States is taken up by the home market, the straight distilled spirit being exported. This process increases the possible yield of spirit from an average of 5 to 10% on the crude oil to 50 to 80% of the crude oil, which alters the entire aspect of the motor spirit problem.

In the present position there is little fear of a motor spirit shortage until there is a shortage of all petroleum products. The question now resolves itself into one of which product can stand the highest price. Probably lubricating oils and medicinal products could command the highest prices. After these come motor spirit, then illuminating oils, then heavy oils for oil engines, and lastly furnace oils. Therefore the supply of furnace oils will suffer most by the introduction of cracking.

The majority of the people engaged in the petroleum industry do not expect any petrol shortage, at any rate for several years to come, in spite of the rapidly increasing demand.

The shale oil supply is less than $\frac{1}{2}$ per cent. of the world's petroleum supply.

Benzol is at present the main petrol substitute. The principal sources of benzol are coal tar and coke oven gas. Gray and Mellanby estimate the possible yield in the United Kingdom, if all benzol were recovered from these sources, as follows :—

From coal tar...........	2	million gallons per annum.
From coke oven gas...	26	,, ,, ,,

An enormous increase in the coal production does not appear probable in the near future, and therefore benzol is not likely to satisfy any large portion of the demand for motor spirit.

The actual production of benzol at the present time is about 10 per cent. of the quantity of petrol imported, and a large part of this is taken up by industries which are in a position to afford higher prices than are acceptable to motorists. At the best, benzol will only make a slight addition to the motor fuel supply. In the opinion of the speaker it will find its best utilisation in the form of mixtures.

The most promising source of petrol substitute at the present appears to be alcohol. Though it is low in heat value (12,697 B.Th.U. gross) it has the advantage of requiring a small amount of air for combustion, and it possesses a high ignition point, and is therefore able to withstand high compression pressures in internal combustion engines. In a suitably designed engine it yields about the same power per gallon as petrol. The possibilities of production of fuel alcohol in this country are not very promising. Dr. Ormandy, who has specialised on this subject for many years, informs me that he considers the most suitable method of preparation to be by the alcoholic fermentation of vegetable matter, and that the necessary vegetable substances can be most economically grown in tropical or subtropical countries. The calcium carbide process could not under existing conditions compete with the fermentation process as regards cost of production.

There is one more point to which I should like to call attention, and that concerns the methods used in valuing motor spirits. Hitherto motor spirit analysis has consisted of routine laboratory tests. These are, however, quite inadequate for this object, and special tests are really required. Though for ordinary commercial purposes the distillation test is sufficiently accurate it is really only being used as a measure of the volatality, which is correctly measured by the vapour tension. Also in the past little notice has been taken of the importance of the ignition point, which is an indication of the maximum engine compression permissible, of which the thermal efficiency is a direct function.

The use of mixed fuels is yet in its infancy, but if maximum economy is to be obtained it will be necessary to employ a standard mixture as motor spirit for general use and to adjust the engine compressions to the corresponding permissible value. At present about 25 per cent. of the power available in benzol is wasted by the use of fuel in engines which are primarily designed for petrol.

Another advantage of the employment of mixtures is that usually two chemically different bodies of approximately the same vapour tension yield mixtures, the vapour tensions of which are higher than those of either constituent. The use of mixtures has already been initiated by the air forces, who have adopted a 20 per cent. benzol and 80 per cent. petrol mixture which possesses several advantages over normal petrol."

Ordinary Meeting, January 30th, 1920.

Mr. R. H. CLAYTON, B.Sc. (*Chairman*), in the Chair.

Dr. R. S. WILLOWS, M.A., opened a debate on "**Recent Work on Colloids.**"

For the purpose of the address colloids were defined as matter in a fine state of subdivision, which consequently possesses a very large surface area. *E.g.*, if a cube of 1 cm. side is divided into cubes whose sides are one-millionth of a cm. the total surface is 60 sq. metres. With each sq. cm. of surface a definite amount of energy is known to be associated, and the difference between colloidal and other matter lies in the fact that the possible changes of this energy may entirely govern the physical and chemical behaviour of the colloid although they are negligible for matter in bulk. If the presence of a solute lowers the surface energy of a solvent, the solute will concentrate itself in the surface, thereby causing a maximum energy decrease. This excess concentration is called *adsorption*.

Instances of this adsorption effect which have important applications are :—The clearing of turbid solutions by running them through an adsorbent such as charcoal; it is probably a first step in many dyeing operations and catalytic reactions; bacteria are removed from water by filtration through sand. McBain and others have shown in some instances that adsorption is followed by solution.

Sols are suspensions of very small particles in a suitable liquid. The particles have an electrical charge whose sign depends on the method of preparation, and not, as frequently stated, only on the chemical character of the substance. By the *X*-ray method they are found to be crystalline, although from their optical behaviour they are known to be nearly spherical in shape. Ellis has shown for emulsions that a *small* reduction in the electrical charge produces precipitation. He has also shown that surface tension has little effect in precipitation. Smoluchowski's theory of precipitation was explained.

The work of Thomson, Harkins and Langmuir on polarised molecules and their consequent effects (1) on the spreading of oil films on liquids, (2) on wetting of solids, and (3) on lubrication, were briefly described; as also Langmuir's determination of the length and section of molecules. Sulman's recent paper on mineral separation was mentioned.

Finally, the necessity for the co-operation of chemist and physicist was insisted on, and support was asked towards the establishment of a Chair of Colloids at Manchester University.

Special General Meeting, February 27th, 1920.

Mr. R. H. Clayton, B.Sc. (*Chairman*), in the Chair.

The proposed Rules of the Section were approved for submission to the Council of the Society for confirmation in accordance with No. 93 of the Articles of Association.

A copy of the Rules is available for inspection by any member at the Society's House.

Ordinary Meeting, February 27th, 1920.

Mr. R. H. Clayton, B.Sc. (*Chairman*), in the Chair.

Mr. John Allan, F.C.S., opened a debate on "**Engineering as Applied to the Buildings and Plant in Chemical Works.**"

The expression "engineering" in the above sense involves knowledge much beyond that of an "astute fitter," and some of it is of so particular a type that it might well be required of an exceptionally specialized civil engineer. As applied to buildings the nature of much of this knowledge is obvious, but again there is much that is not so apparent. Thus, for instance, knowledge as to the suitability of ground to carry the foundations of heavy buildings is obvious, but the effect of the soil upon metals which may be embedded in it or of diffused waste waters which may find their way into it, is not on the surface so apparently necessary as it actually is. In the construction of the buildings the ordinary attention to lighting, ventilation and so on is required, but consideration must also be given to the material of which the building and roofs are constructed. Ferro-concrete may be an ideal material for warehouses and the like, but in chemical plants in which the removal of vessels and pipe lines is frequent, it is objectionable on account of the great difficulty which it offers to such re-arrangements.

In the arrangement plant accessibility to all parts should receive first consideration. It is bad policy to bury tanks or pipe lines in the ground as leakages cannot be observed, and repairs are only possible after much labour and difficulty. Where it is necessary to have tanks or other portions of apparatus below the ground level they should be placed in a well with sufficient room for a workaman to move freely round them, observation then becomes possible.

Although hard and fast lines cannot be laid down in the matter, a study of the unit system of construction of plants is frequently profitable. This system enables a plant to be erected with the minimum cost in its erection so far as drawings, patterns, etc., are concerned, and further, if any portion of a plant consisting of a number of units breaks down, the effect upon the output of the whole plant is considerably less than when the construction is that of one or two very large sections. The adoption of standardization of construction materials would greatly facilitate the employment of the unit system, and even in other cases would simplify erection and extension. It would be necessary, however, before adopting standards to have the uses to which the materials are to be applied very carefully thought out, thus, whilst it is common to use earthenware drain pipes as conduits for gases in chemical works, these are invariably much too heavy for the work they have to do, with the result that supports are infinitely stronger than is necessary and much labour is involved in erecting or renewing the pipe lines. Such heavy pipes as are used in this country are rarely seen in continental works where light earthenware specially constructed for this purpose is employed.

The centralising of units of power, steam supply, etc., may be economical or wasteful according to circumstances, and attention should be given wherever possible to the grouping of buildings housing particular operations, so that solid materials can be handled in buildings in proximity to each other and to the means of transport. Operations involving the use of steam should be carried on in buildings grouped round the central steam supply, such arrangements involving the minimum of losses which arise from radiation and other causes. A variety of points connected with the construction of drying plant, mixing apparatus, and the use of corrodible metals, were also gone into.

Annual General Meeting, April 30th, 1920.

Mr. R. H. CLAYTON, B.Sc. (*Chairman*), in the Chair.

The following Members were elected Officers of the Section and Members of the Committee for the ensuing year:—

Chairman: J. H. LESTER, M.Sc., F.I.C.
Vice-Chairman: R. H. CLAYTON, B.Sc.
Hon. Secretary: DAVID CARDWELL, M.Sc., F.I.C.

Other Members of the Committee: EDWARD ARDERN, D.Sc., F.I.C.; F. W. ATACK, B.Sc., M.Sc.Tech., F.I.C.; W. H. BENTLEY, D.Sc., F.C.S.; Professor ARTHUR LAPWORTH, D.Sc., F.R.S., F.I.C.; HAROLD MOORE, M.Sc.Tech., F.C.S., A.I.C.; Professor F. LEE PYMAN, D.Sc., Ph.D., F.I.C.; RONA ROBINSON, M.Sc., A.I.C.; LEONARD E. VLIES, F.C.S., F.I.C.; and T. R. WOLLASTON, M.I.Mech.E.

Ordinary Meeting, April 30th, 1920.

Mr. J. H. LESTER, M.Sc., F.I.C. (*Chairman*), in the Chair.

Dr. J. A. RUSSELL HENDERSON, F.C.S., read a paper entitled

"Alchemy and Chemistry amongst the Chinese."

Chinese alchemy is of great antiquity and is closely connected with the religion of Tao, which is indigenous to China and which dates back to the sixth century B.C., if not to the beginning of the Chinese race. The alchemists in China had the same objects in view as those in Europe at a much later time, viz., immortality and the transmutation of base metals into gold; their writings are obscure and they failed in their great quest as did the alchemists of the west. However, the studies of the Chinese alchemists led to discoveries of practical importance in metallurgy, mineralogy and botany. China abounds in natural wealth and the Chinese have not been slow to avail themselves of this and to use it to their own advantage. The Chinese show great skill in metallurgy and in the manufacture of pigments, lacquers, poreclain, paper, etc. They very early discovered the explosive properties of gunpowder and made use of it in their wars.

The great mineral and vegetable wealth of China gives promise of a great chemical industry in the future. Methods at present in use are primitive, but modern methods and machinery are beginning to be employed and one can confidently look forward to the time when the latest methods will be used in the exploitation of the vast deposits of coal, iron and other metallic ores, and in the production of oils, essential oils and medicinal substances from vegetable sources.

MANCHESTER
LITERARY AND PHILOSOPHICAL SOCIETY.

Annual Report of the Council, April 1920.

The Society had at the beginning of the Session an ordinary membership of 143. Since then 200 new members have joined the Society (146 of these becoming members by the incorporation of the Manchester Chemical Club). Thirteen members have resigned, and four members (Mr. MARCUS ALLEN, Mr. S. W. GILLETT, Mr. A. J. KING and Mr. HERMANN WOOLLEY) have died. There are, accordingly, at the end of the session, 326 ordinary members of the Society. The Society has also lost by death six honorary members, viz.: Professor W. G. FARLOW, Professor ERNST HAECKEL, Ph.D., Professor J. W. HITTORF, Sir ROBERT H. INGLIS PALGRAVE, F.R.S., The Right Hon. LORD RAYLEIGH, O.M., M.A., D.C.L., Sc.D., F.R.S., and Dr. A. G. VERNON-HARCOURT, M.A., F.R.S.

On the nomination of the Council, Mr. J. T. F. BISHOP, Mr. W. S. CURPHEY, F.I.C., and Mr. C. W. SUTTON, M.A., have been elected corresponding members of the Society.

Twenty-one papers have been read at the Society's meetings during the year; six shorter communications have also been made. In addition, five meetings and a soirée have been held by the Chemical Section.

Sir Henry A. Miers, M.A., D.Sc., F.R.S., Vice-Chancellor of the Victoria University of Manchester, was elected President in November, Professor G. Elliot Smith having been compelled to resign that office on his acceptance of the Professorship of Anatomy in the University of London. At the request of the Council, Professor F. E. Weiss, D.Sc., F.R.S., consented to act as Deputy Chairman when Sir Henry Miers could not attend the Society's meetings.

A new honorary office of Curator has been instituted, and the number of ordinary members of the Council increased from six to nine. Further, the Chairman and the Honorary Secretary of the Chemical Section have been made *ex-officio* members of the Council.

Society's Accounts.

The cash account of the Society is appended to this report. The net cash in hand at the close of the Session amounted to

£46 15s. 9d. On the other hand, the General Account is debtor to the Wilde Endowment Fund to the extent of £381 19s. od., to the Joule Memorial Fund £108 12s. od., to the Natural History Fund £162 3s. 3d., and, in addition, has a total net indebtedness of about £180.

Society's Library.

The Librarian reports that during the Session 453 volumes have been stamped, catalogued and pressmarked; 415 of these were serials. The total number of volumes catalogued to date is 38,560.

The additions to the library for the Session amounted to 627 volumes: 579 serials, and 48 separate works. The donations (exclusive of the usual exchanges) were 45 volumes; 3 volumes were purchased in addition to those regularly subscribed for. During the year 150 volumes have been bound in 102 covers. In the previous Session the corresponding numbers were 93 volumes in 92 covers.

The additions included "*Chemical Abstracts, Decennial Index Volumes* 1-10 (1907—1916), *Subject Index A—Z,*" in two volumes (8vo., Easton, Pa., 1919), published by the American Chemical Society. The Society now subscribes to *Discovery* and *The Journal of Industrial and Engineering Chemistry.* The donations to the Society's Library during the Session include gifts of books by Mr. C. L. Barnes, Messrs. Edward Bennis & Co., Ltd., Mr. C. E. Stromeyer, the Trustees of the British Museum (Natural History), the Patent Office Library, London; the Director of the Geological Survey of India; the Académie Royale, Brussels; the Bataviaasch Genootschap van Kunsten en Wetenschappen, Batavia; the Yale University Press, New Haven, Conn., U.S.A.; the Bureau of American Ethnology, and the Smithsonian Institution, Washington; and the Department of Commerce, United States Coast and Geodetic Survey. The Optical Society, London (*Transactions*), and the Royal Aëronautical Society (*The Aëronautical Journal*), have been placed on the Society's list of exchanges.

The library continues to be satisfactorily used for reference purposes. 434 volumes have been borrowed from the library during the past year. The number of books borrowed during the previous year was 283 and during 1917-18, 280.

The publication of the Society's *Memoirs and Proceedings* has been continued under the supervision of the Editorial Committee.

Donations.

The Society has received from Mr. Henry Boddington, J.P., of Wilmslow, a valuable etched portrait of Henry D. Pochin, D.Sc., J.P., Mayor of Salford 1866-68.

Other gifts to the Society during the year include a barometer, which belonged to the late Dr. Henry Wilde, presented by the University of Oxford; a photograph of Dr. Wilde, presented by Professor H. B. Dixon, M.A., Ph.D., F.R.S.; and 32 volumes of the Society's *Memoirs and Proceedings*, presented by Mr. John Boyd.

Dalton Medal.

A Dalton Medal (struck in 1864) was unanimously awarded by the Council to Sir Ernest Rutherford, M.A., D.Sc., F.R.S., "in recognition of his brilliant researches in Manchester on the constitution of the atom."

Formation of Chemical Section.

A Chemical Section of the Society was formed and elected the following Officers:—Chairman, Mr. R. H. Clayton; Treasurer, Mr. J. H. Lester; Secretary, Mr. F. W. Atack. Meetings of the Section have been held monthly. On Friday, March 26th, 1920, the Section held a Soirée by invitation of Mr. R. H. Clayton.

Society's House.

In accordance with discussions which have taken place during the last twelve months at meetings of the Society, the Council have carefully considered what steps might be taken to extend the utility of the Society as a centre for literary and scientific intercourse in the Manchester district. Several advances have been made already; for example, a Chemical Section has been formed, and in addition the Manchester Astronomical Society and the Manchester Microscopical Society are holding their meetings in the Society's house. Several meetings of other scientific bodies have been held in the rooms, and informal communications have been received from others with reference to similar privileges.

A recent re-arrangement of two of the Society's rooms has made it possible to provide a comfortable room, supplied with writing-table and current copies of the scientific journals, for the convenience of members. The opening of the premises in the evenings has already been appreciated by a number of members, especially those who are unable to make use of the

Society's room during the daytime. The Society's House is now open to members from 9.30 a.m. to 9,30 p.m. on every week-day except Saturdays, when it is open from 9.30 a.m. to 2 p.m.

Building Extensions and Alterations.

An appeal for funds has been issued to members of the Society in which attention was drawn to the following points:

The Society's house contains no room capable of accommodating more than about one hundred persons, a number which is already exceeded at many of the meetings of certain local societies, and it is clear that if the Society's house is to become the meeting place for local literary and scientific societies, and indeed even to provide for the needs of its own rapidly increasing membership, the premises must be extended.

Fortunately, there exists a small plot of land behind the Society's house which would be suitable for extension, and which has been offered to the Society on acceptable terms. The Council have therefore asked the advice of an architect with a view to discovering whether their needs could be met by extension on this site, with some minor structural alterations to the present building. Plans have been prepared, and a copy of them circulated for the consideration of members. The extension and alterations will provide, amongst other benefits, the following:—

(1) A library and meeting room capable of seating some two hundred persons.
(2) A smaller lecture room for smaller meetings.
(3) Committee room and ladies' common room.
(4) Extended accommodation for books.
(5) Improved lavatory accommodation.

At the same time, there will be no interference with the leading features of the existing house with their historical associations, such as the room used by John Dalton.

It is hoped that members of the Society will appreciate the advantages of the scheme, for its successful consummation will require their active individual collaboration. The cost is estimated at about £8,000, and it is obviously necessary that members of the Society should give the scheme their fullest financial support. For this purpose £1,046 17s. 6d. has already been promised, by 53 members, towards the proposed building extensions and alterations.

NOTE.—The Treasurer's Accounts for the Session 1919-1920 *have been endorsed as follows :*

April 9th, 1920. Audited and found correst.

We have also seen, at this date, the Certificates of the following Stocks held in the name of the Society :—£1,225 Great Western Railway Company 5% Consolidated Preference Stock, Nos. 12,293, 12,294, and 12,323; £7,500 Gas Light and Coke Company Ordinary Stock (No. 8/1960); £100 East India Railway Company 4% Annuity Stock (No. 4032); and the deeds of the Natural History Fund, of the Wilde Endowment Fund, those conveying the land on which the Society's premises stand, and the Declarations of Trust.

Leases and Conveyances dated as follows :—

22nd Sept., 1797.
23rd Sept., 1797.
25th Dec., 1799.
25th Dec., 1799.
23rd Dec., 1820.
23rd Dec., 1820.

Declarations of Trust :—

24th June, 1801.
23rd Dec., 1820.
8th Jan., 1878.

Appointment of New Trustees :—

30th April, 1851.

We have also seen Bankers' acknowledgment of the investment of £300 in the 5% War Loan :—2 Bonds for £100 each, Nos. 71827 and 366270; and 2 Bonds for £50, Nos. 131577 and 31358.

We have also verified the balances of the various accounts with the bankers' pass books.

(*Signed*) J. WILFRID JACKSON.
R. S. WILLOWS.

MANCHESTER LITERARY

Dr. *W. Henry Todd, Treasurer, in Account with th*

	£	s.	d.	£	s.	d.
To Balance, 1st April, 1919...				25	10	
To Members' Subscriptions :—						
Half Subscriptions, 1918-19, 1 at £1 1s. od.	1	1	0			
" 1919-20, 13 " "	13	13	0			
" 1920-21, 1 " "	1	1	0			
Subscriptions :— 1915-16, 1 at £2 2s. od.	2	2	0			
" 1916-17, 1 " "	2	2	0			
" 1917-18, 3 " "	6	6	0			
" 1918-19, 7 " "	14	14	0			
" 1919-20, 128 " "	268	16	0			
" 1920-21, 1 " "	2	2	0			
" 1919-20, 10 at £1 1s. od. (½ year)	10	10	0			
				322	7	0
To Life Composition Fee				26	5	0
To Manchester Chemical Club :— 14[illegible] Members at £2. 2s. od.				306	12	0
To Sale of Publications :—						
Memoirs and Proceedings	22	18	1			
Catalogues	0	18	6			
				23	16	7
To W. R. Halkyard, Donation towards Plates ...				60	0	0
To Henry Wilde's Executors, Cost of Setting up Paper				3	0	0
To Transfers from Wilde Endowment Fund :—						
Rent of Rooms	50	0	0			
Entrance Fees	12	12	0			
Half Subscriptions	17	17	0			
				80	9	0
To Dividends :—						
Natural History Fund	42	17	6			
Joule Memorial Fund	15	2	8			
Wilde Endowment Fund	7	0	0			
				65	0	2
To Special Donations :—						
R. H. Clayton	100	0	0			
F. W. Atack	20	0	0			
				120	0	0
To Soirée Donations :—						
William Thomson	15	0	0			
Council	9	7	0			
				24	7	0
To Loans from Wilde Endowment Fund				381	19	0
To Bank Interest				0	19	4
To Expenses of Meetings :—						
Manchester Microscopical Society	5	0	0			
" Chemical Club	4	10	0			
" Section, Institute of Chemistry ...	4	12	9			
				14	2	9
To Wilde Portraits				6	6	0
To National Health Insurance Act deductions ...				1	16	10
				£1,462	10	8

AND PHILOSOPHICAL SOCIETY.

Society, from 1st April, 1919, to 31st March, 1920. **Cr.**

	£	s.	d.	£	s.	d.
By Overdraft at Williams Deacon's Bank, 1st April, 1919 ..				164	14	10
By Charges on Property :—						
Chief Rent	9	0	10			
Income Tax and Inhabited House Duty	3	17	4			
Insurance against Fire	11	0	0			
				23	18	2
By House Expenditure :—						
Coal, Gas, Electric Light, Water, etc.	47	10	1			
Tea, Coffee, etc., at Meetings	40	0	1½			
Cleaning, Washing, etc....	8	10	11			
Replacements	15	3	3½			
Repairs, etc.	22	3	7½			
Carpet Cleaned, etc.	4	7	9			
Chairs Re-seated	8	8	0			
Clock Cleaned	0	15	0			
Busts Cleaned	4	0	0			
Common Room Decorated	39	10	0			
Blinds	4	6	0			
Wilde Photos, etc.	10	3	0			
Herbarium Cabinet...	7	7	6			
				212	5	3½
By Administrative Charges :—						
Assistant Secretary's Salary	83	6	8			
Acting " "	25	0	0			
Caretaker and Housekeeper...	97	10	0			
Servant	6	10	0			
Extra Attendance at Meetings	20	7	6			
Postages, Carriage of Parcels, "Memoirs" ...	37	9	5½			
Stationery, Cheques, Receipts, Engrossing etc.	36	5	7			
Insurance against Liability	1	11	2			
National Health Insurance Stamps	3	9	4			
Miscellaneous Expenses	3	10	9			
				315	0	5½
By Publishing :—						
Printing "Memoirs and Proceedings," and Illustrations, Circulars, etc.				320	16	11
By Library :—						
Periodicals (except those charged to Natural History Fund)				19	3	8
By Soirée Expenses				31	5	7
By Institute of Chemistry Meeting				4	12	9
By Setting up Wilde Paper				3	0	0
By Manchester Chemical Club, Purchase of Stock				264	1	3
By Bank Interest on Overdraft etc.				4	18	6
By Natural History Fund :—						
(Items shown in Balance Sheet of this Fund)				26	13	9
By Wilde Endowment Fund :—						
Dividend Refunded (War Loan)				7	0	0
By Balance at Williams Deacon's Bank, 1st April, 1920	54	19	6			
By Balance in Treasurer's Hands	10	0	0			
				64	19	6
				£1,462	10	8

MANCHESTER LITERARY AND PHILOSOPHICAL SOCIETY.

Dr. *W. Henry Todd, Treasurer, in Account with the Society, from 1st April, 1919, to 31st March, 1920.* **Cr.**

	£	s.	d.	£	s.	d.
To Balance, 1st April, 1919...				25	10	0
To Members' Subscriptions :—						
Half Subscriptions, 1918-19, 1 at £1 1s. 0d.	1	1	0			
" 1919-20, 13 " "	13	13	0			
" 1920-21, 1 " "	1	1	0			
Subscriptions :— 1915-16, 1 at £2 2s. 0d.	2	2	0			
" 1916-17, 1 " "	2	2	0			
" 1917-18, 3 " "	6	6	0			
" 1918-19, 7 " "	14	14	0			
" 1919-20, 128 " "	268	16	0			
" 1920-21, 1 " "	2	2	0			
" 1919-20, 10 at £1 1s. 0d. (½ year)	10	10	0	322	7	0
To Life Composition Fee				26	5	0
To Manchester Chemical Club :—						
146 Members at £2. 2s. 0d.				306	12	0
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				23	16	7
To W. R. Halkyard, Donation towards Plates				60	0	0
To Henry Wilde's Executors, Cost of Setting up Paper				3	0	0
To Transfers from Wilde Endowment Fund :—						
Rent of Rooms	50	0	0			
Entrance Fees	12	12	0			
Half Subscriptions	17	17	0			
				80	9	0
To Dividends :—						
Natural History Fund	42	17	6			
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Wilde Endowment Fund	7	0	0			
				65	0	2
To Special Donations :—						
R. H. Clayton	100	0	0			
F. W. Atack	20	0	0			
				120	0	0
To Soirée Donations :—						
William Thomson	15	0	0			
Council	9	7	0			
				24	7	0
To Loans from Wilde Endowment Fund				381	19	0
To Bank Interest				0	19	4
To Expenses of Meetings :—						
Manchester Microscopical Society	5	0	0			
" Chemical Club	4	10	0			
" Section, Institute of Chemistry	4	12	9			
				14	2	9
To Wilde Portraits				6	6	0
To National Health Insurance Act deductions				1	16	10
				£1,462	10	8

	£	s.	d.	£	s.	d.
By Overdraft at Williams Deacon's Bank, 1st April, 1919				164	14	10
By Charges on Property :—						
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Replacements	15	3	3½			
Repairs, etc.	22	3	7½			
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Blinds	4	6	0			
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				212	5	3½
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Acting " "	25	0	0			
Caretaker and Housekeeper	97	10	0			
Servant	6	10	0			
Extra Attendance at Meetings	20	7	6			
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Stationery, Cheques, Receipts, Engrossing etc.	36	5	7			
Insurance against Liability	1	11	2			
National Health Insurance Stamps	3	9	4			
Miscellaneous Expenses	3	10	9			
				315	0	5½
By Publishing :—						
Printing "Memoirs and Proceedings," and Illustrations, Circulars, etc.				320	16	11
By Library :—						
Periodicals (except those charged to Natural History Fund)				19	3	8
By Soirée Expenses				31	5	7
By Institute of Chemistry Meeting				4	12	9
By Setting up Wilde Paper				3	0	0
By Manchester Chemical Club, Purchase of Stock				264	1	3
By Bank Interest on Overdraft etc.				4	18	6
By Natural History Fund :—						
(Items shown in Balance Sheet of this Fund)				26	13	9
By Wilde Endowment Fund :—						
Dividend Refunded (War Loan)				7	0	0
By Balance at Williams Deacon's Bank, 1st April, 1920	54	19	6			
By Balance in Treasurer's Hands	10	0	0			
				64	19	6
				£1,462	10	8

JOULE MEMORIAL FUND, 1919-1920. (Included in the General Account, above.)

		£ s. d.			£ s. d.
To Balance, 1st April, 1919 ...		93 9 4	By Balance, 1st April, 1920 ...		108 12 0
To Dividends :—					
Dividend on £100 East India Railway Company's 4% Annuity Stock ...	6 7 8				
Interest on £250 5% War Loan Stock ...	8 15 0				
		15 2 8			
		£108 12 0			£108 12 0

NATURAL HISTORY FUND, 1919-1920. (Included in the General Account, above.)

		£ s. d.			£ s. d.
To Balance, 1st April, 1919 ...		145 19 6	By Natural History Periodicals ...		15 2 6
To Dividends on £1,225 Great Western Railway Company's Stock ...		42 17 6	By Subscriptions :—		
			Entomological Society, 1919 and 1920 ...	2 2 0	
			Lancashire and Cheshire Fauna Committee, 1919...	1 1 0	
			Paleontographical Society, 1917 ...	1 1 0	
			Ray Society, 1920 ...	1 1 0	
					5 5 0
			By Binding Natural History Periodicals ...		6 6 3
			By Balance, 1st April, 1920 ...		162 3 3
		£188 17 0			£188 17 0

WILDE ENDOWMENT FUND, 1919-1920.

		£ s. d.			£ s. d.
To Balance, 1st April, 1919 ...		171 0 4	By Assistant Secretary's Salary ...		137 10 0
To Dividends on £7,500 Gas Light and Coke Company's Ordinary Stock ...		157 10 0	By Acting " " ...		12 10 0
To Interest on War Loan Stock :—			By Maintenance of Society's Library :—		
On £350 for 6 months ...	6 2 6		Binding Books ...		24 19 9
On £50 for 6 months ...	0 17 6		By Loan to Society's Funds :—		
		7 0 0	Sale of £300 War Loan Stock ...	281 19 0	
To Sale of £300 War Loan Stock ...		281 19 0	Printing of Memoirs ...	100 0 0	
To Bank Interest ...		1 18 10			381 19 0
To Overdraft at Williams Deacon's Bank, 1st April, 1920 ...		18 3 9	By Transfer to Society's Funds :—		
			Rent of Rooms ...	50 0 0	
			Entrance Fees ...	12 12 0	
			Half Subscriptions ...	17 17 0	
					80 9 0
			By Cheque Book ...		0 4 2
		£637 11 11			£637 11 11

THE COUNCIL AND MEMBERS OF THE MANCHESTER LITERARY AND PHILOSOPHICAL SOCIETY.

1919-20.

President.
Sir HENRY A. MIERS, M.A., D.Sc., F.R.S.

Vice-Presidents.
W. W. HALDANE GEE, B.Sc., M.Sc.Tech., A.M.I.E.E.
FRANCIS JONES, M.Sc., F.R.S.E., F.C.S.
R. L. TAYLOR, F.C.S., F.I.C.
WILLIAM THOMSON, F.R.S.E., F.C.S., F.I.C.

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GEORGE HICKLING, D.Sc., F.G.S.
H. F. COWARD, D.Sc., F.I.C.

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W. HENRY TODD.

Librarian.
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MEMOIRS AND PROCEEDINGS

OF THE

MANCHESTER LITERARY & PHILOSOPHICAL SOCIETY

(MANCHESTER MEMOIRS.)

VOLUME LXV (1920-21)

MANCHESTER:
36, GEORGE STREET
1922

NOTE.

THE authors of the several papers contained in this volume are themselves accountable for all the statements and reasonings which they have offered. In these particulars the Society must not be considered as in any way responsible.

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MEMOIRS AND PROCEEDINGS

OF

THE MANCHESTER LITERARY & PHILOSOPHICAL SOCIETY, 1920-21.

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MANCHESTER:
36, GEORGE STREET.

Price Twelve Shillings.

July 27th, 1921.

Manchester Memoirs, Vol. lxv. (1921), *No.* 1

I. Notes on a Collection of Hepatics from the Cameroons, West Coast of Africa.

By William Henry Pearson, M.Sc., A.L.S.

(Received and read November 2nd, 1920.)

I received this small collection some time ago from Mr. W. G. Travis, who wrote: "These Hepatics grew in small quantity among mosses, on logs of ebony, imported into Liverpool from the Cameroons, the port of shipment being Duala. The bark is removed from these ebony logs, and evidently the wood has been lying out in the open somewhere, no doubt awaiting shipment, during the war, and this has given a chance for the hepatics, evidently terricolous species, to develop on earth in hollows in the wood."

Two papers have been written by Mitten (**1**) on the Hepatics of the Cameroons and the West Coast of Africa, and a considerable number of species has been recorded from there by Stephani (**2**).

The following is a list of species I have found in the Collection. Type specimens of this Collection are in the Manchester Museum. The terms used to define the size of plant and cell are those proposed by Dr. Spruce.

Aneura Travisiana, n.sp. Pearson.

Dioicous. Small, pale yellow colour, intricately cæspitose. Stems irregularly sub-pinnate; trunk narrowly winged, wings 1 to 2 cells wide; on cross-section plano-convex, 4 cells thick at the middle, outer cells small, the two inner large; branch midrib 4 to 6 cells wide, cells moderate to rather large in size, oblong-quadrate, wings 3 to 4 cells wide, same size as those of the mid-rib only quadrate; branchlets often digitate (three lobes), attenuate, thin. Bracts at the base of calyptra ovate-acuminate. Calyptra cylindrical, oblong-clavate, smooth. Amentula slender, narrow, alveoles in two rows, 5-10 pairs, denticulate.

March 31st, 1921.

Dimensions.—Stems 1 cm. long; trunk .3 mm. wide; branches .4 mm. wide; .1 mm. thick at the middle, upper layer of cells .04 mm., cells of mid-rib 1.0 mm. by .05 mm., cells of wings .05 mm., bracts of calyptra .3 mm. by .15 mm. at middle, calyptra 1.5 mm. by .25 mm., capsule .5 mm. by .15 mm., amentula .1 mm. by .2 mm.

Hab.—Collected on ebony imported into Liverpool Docks, January 1920, from the Cameroons, West Coast of Africa, by Mr. W. G. Travis, a keen Liverpool botanist, whose name I have the pleasure of associating with the plant.

Observations.—This is one of the smallest *Aneuræ* known; as the ♂ and ♀ are perfectly developed, I have no doubt as to its being its normal size. *Aneura limbata,* St., from the Cameroons, which I have had the opportunity of examining, is a plant twice its size, with much more distinct wings, calyptra clavate, hairy.

A curious feature about the plant is that the upper layer is composed of smaller cells, with very delicate walls; in the next layer, which is the most prominent, the cells are larger with thicker walls; the mid-rib is composed of elongated cells. In *Aneura limbata,* St., the mid-rib has elongated cells, but the cells of the wings are smaller, giving the plant a very winged appearance.

Description of *Plate* I. *Fig.* 1. Plant nat. size. *Fig.* 2. Fertile stem × 16. *Figs.* 3, 4. Cross-section of stem × 50. *Figs.* 5, 6. Ditto, of branch × 50. *Figs.* 7, 8. Ditto of branchlets × 50. *Fig.* 9. Upper layer of cells × 290. *Fig.* 10. Inner layer of cells × 290. *Fig.* 11. Bract, base of calyptra × 50. *Fig.* 12. Calyptra × 24. *Fig.* 13. Ditto × 50. *Fig.* 14. Capsule × 50. *Fig.* 15. Male stem with amentula × 24.

Lophocolea Newtoni, St.

Observations.—The admirable geographical classification of Stephani's "Sp. Hep." enables a student to arrive at a satisfactory determination of a species with some certainty; there are 4 species with long, bidentate leaves recorded from the West Coast of Africa, and my specimens agree with the description of *L. Newtoni* from the Cameroons, collected by Zenker; leaves oblong, triangular, apex twice as narrow as base, bispinose, segments sub-equal, short, narrow, divergent, no trigones, underleaves quadrifid to the middle, segments narrowly lanceolate.

MASTIGOLEJEUNEA — (?).

Observations.—I picked out 3 or 4 broken stems of a species belonging either to this genus or *Thysananthus* Lindenb.; leaves oblong, acute, lobule oblong-quadrate; underleaves entire, broadly cuneate, apex retuse, some emarginate. I saw one young underleaf bifid; no species belonging to either of these genera with these characters are recorded from West Africa; it is probably a new species, but more material is wanted to make sure.

MARCHESINIA EXCAVATA (Mitt.), St.

The few stems met with agree well with Mitten's description and figures, where all the leaves are drawn as bi-apiculate; in my specimens they are either all so, or simply apiculate, stem about 8 narrow cells wide, leaves oblong, .8 mm. by .6 mm. (Stephani says "ovato-ligulate"), upper margin round, ampliate, covering or crossing the stem, often recurved at the base; lobule oblong-quadrate, angle acute or rounded, complanate above, keel slightly swollen; underleaves contiguous, orbicular, slightly decurrent.

DREPANOLEJEUNEA — (?).

Sterile. Minute, pale green. Stems simple, viewed antically a little more than 2 cells wide. Leaves contiguous or slightly distant, slightly concave, contorted, lobe patent-divergent (70°), semi-ovate-oval, upper margin arcuate, extending to stem but not covering it, narrow base insertion, lower margin slightly curved, apex acute, the whole margin of leaf minutely denticulate, rarely crenulate, cuticle smooth, lobule patent (50°) about one-third smaller than the lobe, rotund or oblong-rotund, free margin involute, unidentate, tumid, keel smooth; cells roundish, very small to small, walls thick, no trigones, marginal cells triangular, acute, teeth unicellular. Underleaves slightly broader than the stem, broadly obovate or cuneate, bifid to the middle, segments acute, 1-2 then 3 cells wide at the base.

Dimensions.—Stems $\frac{1}{8}$th to $\frac{1}{4}$ inch long, .04 mm. diam.; with leaves .65 mm. wide; leaves, lobe .375 mm. by .3 mm., .35 mm. by .25 mm., .3 mm. by .25 mm.; lobule .15 mm. long by .1 mm. high; cells .02 mm. by .015 mm., .02 mm. by .02 mm. by .02 mm., marginal teeth .02 mm. by .015 mm.; underleaves .075 mm. by .075 mm., .05 mm. by .05 mm., segments .03 mm.

Observations.—As I have only met with two stems of this minute species I hesitate to name it, although Stephani (3) in his "Sp. Hep." does not record any *Drepanolejeunea* from Africa with margin of leaves minutely denticulate.

CERATOLEJEUNEA SAXBYI, n.sp. Pearson.

Monoicous. Medium size; reddish-brown in colour; loosely cæspitose or creeping amongst other mosses or hepatics. Stems irregularly pinnate, alternate, 2 to 3 cells wide, innovant branch arising from base of perianth, sometimes long and again innovant, rarely two innovant branches. Leaves horizontal or slightly ascending, imbricate, slightly concave, semi-rotund or oblong, apex acute or more rarely obtuse, margin entire, upper margin rounded, ampliate, crossing the stem, lower margin nearly straight or slightly curved, branch leaves sometimes ovate-acute, distantly denticulate; cells quadrate or oblong-quadrate, middle and basal cells medium size, marginal cells very minute, a remarkable gradation in size from the middle to the margin, no trigones; ocellate, 1-2, or sometimes more, ocelli oblong, near the base; lobule very small, about 5 times smaller than the lobe, oval or oblong, free margin unidentate, tumid, keel rounded, smooth, lobule sometimes reduced to a mere line or wanting. Underleaves 3 to 4 times broader than the stem, approximate, broadly ovate, bifid to one-third, segments acute, sinus acute, rarely rounded. Bracts rotund, apex acute, sparingly denticulate, lobule 2 to 3 times smaller, oval, sparingly denticulate or entire. Bracteole oblong-oval, bifid to one-third, segments acute, sinus acute. Perianth ovate, upper portion 5-keeled, keels smooth, mouth with 4 horns. Amentula sessile, short, 2 to 3 pairs of bracts; bracts, lobe rotund, apex obtuse, lobule slightly smaller, oval, apex obtuse. Water sacs (utricles) more or less present on the stems.

Dimensions.—Stem $\frac{1}{2}$ to 1 inch long; .075 mm. diam.; with leaves 1.25 mm. wide; leaves .7 mm. by .45 mm., .65 mm. by .45 mm., .6 mm. by 4 mm., lobule .15 mm. by .1 mm.; cells, middle .03 mm., .04 mm. by .03 mm., ocelli .05 mm. by .03 mm., marginal .01 mm.; underleaves .4 mm. by .4 mm., .35 mm. by .35 mm., .35 mm. by .3 mm., segments .075 mm.; bracts, lobe .7 mm. by .5 mm., lobule .4 mm. by .2 mm.; bracteole .5 mm. by .375 mm.; perianth .6 mm. by .4 mm.; male bracts, lobe .2 mm. by .15 mm., lobule .15 mm. by .1 mm.

Hab.—Tarkwa, Prestea District, Gold Coast, 1911, H. H. Saxby, and on ebony logs from the Cameroons, Liverpool Docks, H. G. Travis, Feb. 1920.

Observations.—In addition to the few stems of this species detected in the hepatics forwarded to me by Mr. Travis from the Cameroons, I have received from Mr. Wm. Ed. Nicholson, of Lewes, a packet of the same species collected on the Gold Coast, West Africa, by Mr. H. H. Saxby, in which there were very fine and perfect stems, and I have pleasure in naming the species after this gentleman, who has made a very interesting collection of Hepatics in West Africa.

Stephani in his "Sp. Hep." (4) describes a number of *Ceratolej.* from the West Coast of Africa, but to none of them can be referred *C. Saxbyi* according to his descriptions.

C. calabariensis, St., has obtuse leaves, with large lobules, underleaves 5 times broader than the stem, and divided to the middle.

C. diversicornua, St., leaves minutely denticulate, lobule large, oblong.

C. florabunda, St., leaves ovate, apex acute, near apex paucidentate; underleaves elliptic, bilobed to the middle, lobes lanceolate, obtuse; bracts lanceolate, acute.

C. umbonata, St., leaves acute, apex with few teeth, no ocelli, underleaves gigantic, equal in size to the leaves, deeply cordate, bracts apiculate.

C. Zenkeri, St., leaves ovate, apex obtuse, underleaves five times broader than the stem, divided to the middle; bracts small, half the size of perianth, margin entire, bracteole divided to the middle.

Lejeunea acuta, Mitt., *Jour. Linn. Soc.*, Vol. 7-8, p. 167 (1864), from the Cameroons, which Mitten notes as similar to *L. cerina,* L. et L. (a *Ceratolejeunea*) is listed by Stephani (5) as a *Taxilejeunea,* and described as dioicous.

Description of *Plate* II. *Fig.* 1. Plants nat. size. *Fig.* 2. Portion of stem, antical view, × 24. *Fig.* 3. Ditto, postical view, × 50. *Figs.* 4, 5. Lobules of leaves × 50. *Figs.* 6-8. Leaves × 50. *Fig.* 9. Portion of leaf, showing ocellum × 290. *Fig.* 10. Ditto, near margin × 290. *Fig.* 11. Underleaves × 50. *Fig.* 12. Bract × 50. *Fig.* 13. Bracteole × 50. *Fig.* 14. Perianth × 50. *Fig.* 15. Portion of stem with amentulum × 50.

CHEILOLEJEUNEA PRINCIPENSIS, St.

Observations.—The specimens fairly well agree with the type (Ex. herb. Stephani, Manchester Museum) only rather laxer.

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4. —— "Sp. Hep.," Vol. v, p. 391, 1913.
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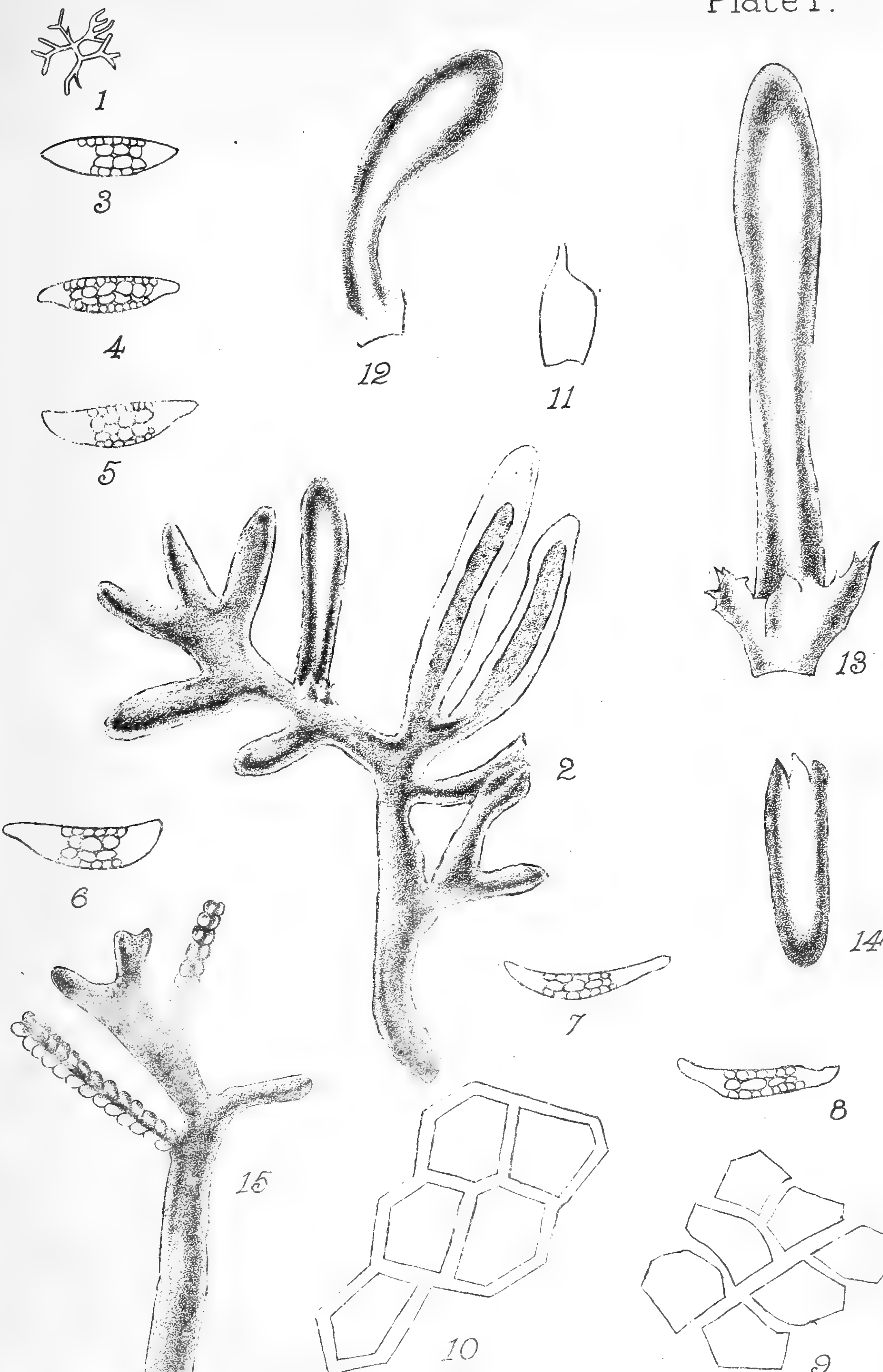
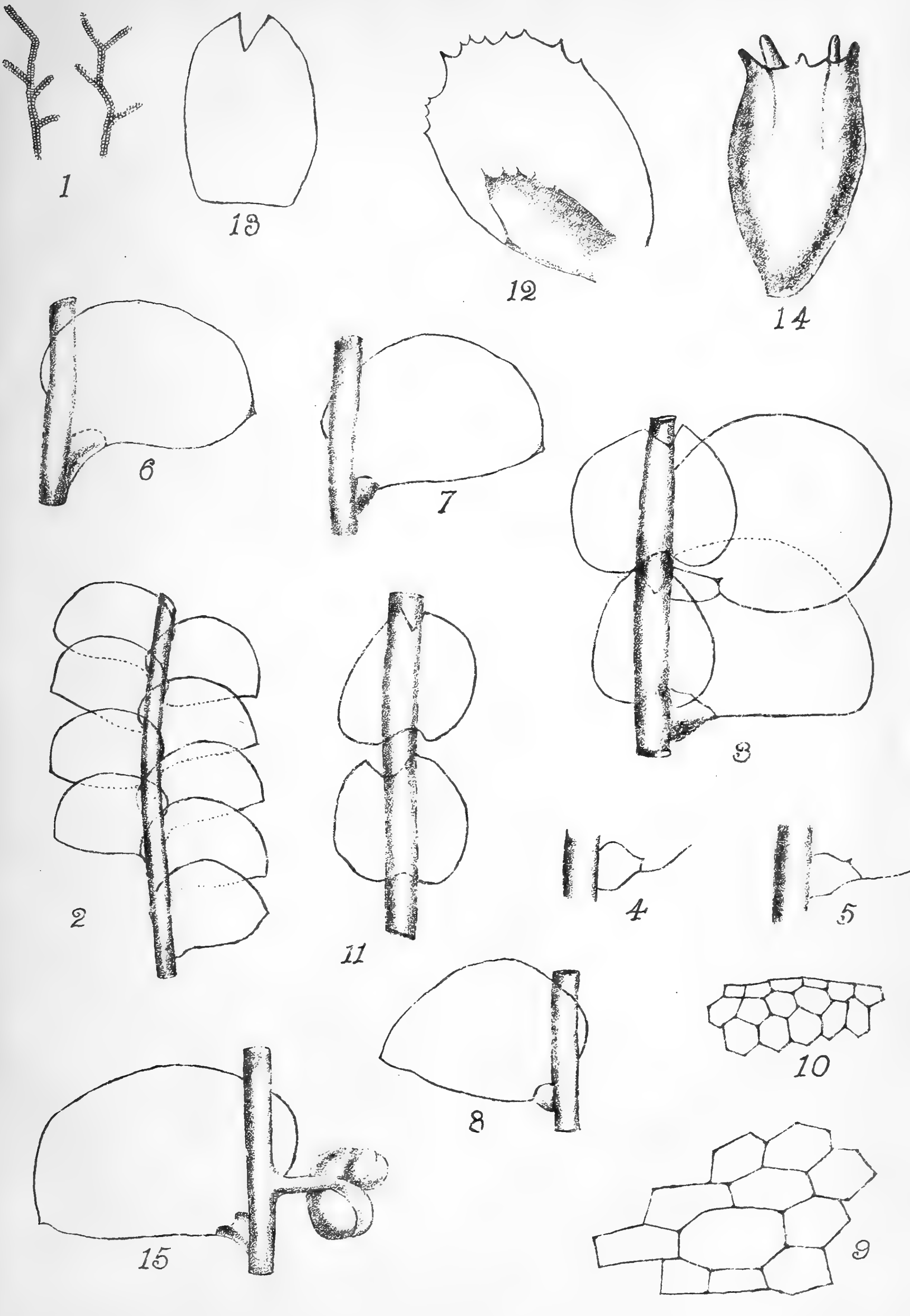
Plate I.



ANEURA TRAVISIANA

W.H.P. del.

Plate II.



CERATOLEJEUNEA SAXBYI

W.H.P.del.

Manchester Memoirs, Vol. lxv. (1921), *No.* 2

II.—The Polytropic Curve and Its Relation to Thermodynamic Efficiency. (With Note on the Uniflow Engine).

By W. J. WALKER, Ph.D., B.Sc., A.M.Inst.C.E.,
Lecturer in Mechanical Engineering in the College of Technology, Manchester.

(*Received June 24th, 1920. Read November 2nd, 1920.*)

INTRODUCTION. The writer's interest in this subject began when engaged on a theoretical enquiry into the efficiency of an Otto cycle gas engine as affected by water injection[1] during the compression stroke. Since that time the opportunity of carrying out experimental work on the subject has presented itself. From these experiments, an account of which it is hoped will be published at an early date, it appears that water injection (no matter at what portion or during what period of the engine cycle injection takes place) does undoubtedly diminish the efficiency, although to a slight extent only. The physical interest in the problem, however, lies in asking why this should be so.

The polytropic system of curves is defined as "that system representing the relation between any two of the quantities, pressure, volume, or temperature of a gas, when the quantity of heat supplied to or withdrawn from the gas is directly proportional to the change of temperature."

Thus if

$$dQ = kdT \qquad - \quad - \quad - \quad - \quad - \quad (1)$$

where k is some constant, the corresponding mathematical relationship between pressure and volume is readily obtained and is as follows :—

$$pv^n = \text{constant} \qquad - \quad - \quad - \quad - \quad (2)$$

where n is constant and equal to $\dfrac{k-K_p}{k-K_v}$ K_p and K_v being the specific heats of the gas at constant pressure and constant volume respectively.

1. "Internal Combustion Engineering," June 10th, 1914.

The simple expression (2) gives a "double infinity" of curves comprising each infinite series of lines in which "n" has some definite value, which may be any positive, negative, integral or fractional number. Well known polytropic lines are, the adiabatic lines when $n=\frac{K_p}{K_v}=\delta$, isothermal lines when $n=1$, constant volume lines when $k=K_v$, constant pressure lines when $k=K_p$, and straight lines radiating from the origin when $n=-1$.

For the purpose of the present investigation the thermodynamic cycles shown in *Figs.* 1 and 2 have been chosen as representing, perhaps, the most general types, limiting cases of which may be taken to represent most of the various thermodynamic cycles on which modern internal combustion engines are operated.

Cycles such as those shown in *Figs.* 1 and 2 have already been termed by the writer "Dual Combustion Cycles,"[2] on account of the fact that heat is imparted to the working fluid by internal combustion both at constant volume and constant pressure. The only difference between the two cycles is, as shown, that when the fluid is in the state $p_4 v_4 T_4$, in either case, the state $p_0 v_0 T_0$ is arrived at in the one case, represented by *Fig.* 1, by the same type of polytropic compression throughout the whole of the stroke, while in the second cycle, represented by *Fig.* 2, the same state $p_0 v_0 T_0$ is arrived at after two types of polytropic compression, namely, constant pressure compression for the first part of the stroke and then adiabatic compression for the remainder of the stroke.

Fig. 1 represents the type of cycle in which the value of the index of "V" in the compression curve is affected by various factors, either accidental, such as heat conduction to or from the cylinder walls, or intentional, such as the injection of water spray for the purpose of keeping down the temperature during the stroke.

The general efficiency expression for this type of cycle is obtained as follows :—

$$\text{Efficiency} = \eta = 1 - \frac{\text{heat withdrawn}}{\text{heat given}}$$

$$\therefore \eta = 1 - \frac{K_v\,(T_3 - T_4) + \frac{\delta - n}{\delta - 1}\left(R\frac{T_0 - T_4}{n - 1}\right)}{K_v\,(T_1 - T_0) + K_p\,(T_2 - T_1)} \qquad (3)$$

2. *Phil. Mag.*, Sept., 1917.

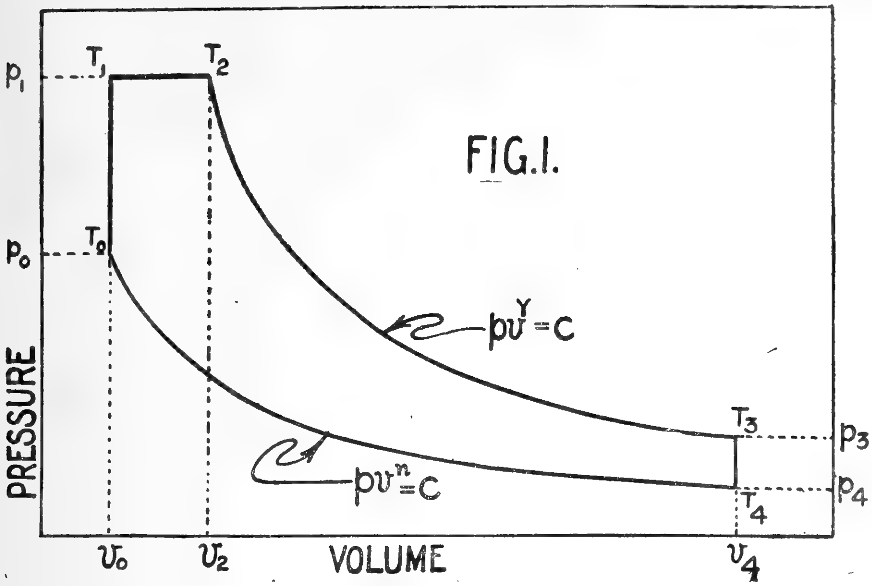


FIG. 1.

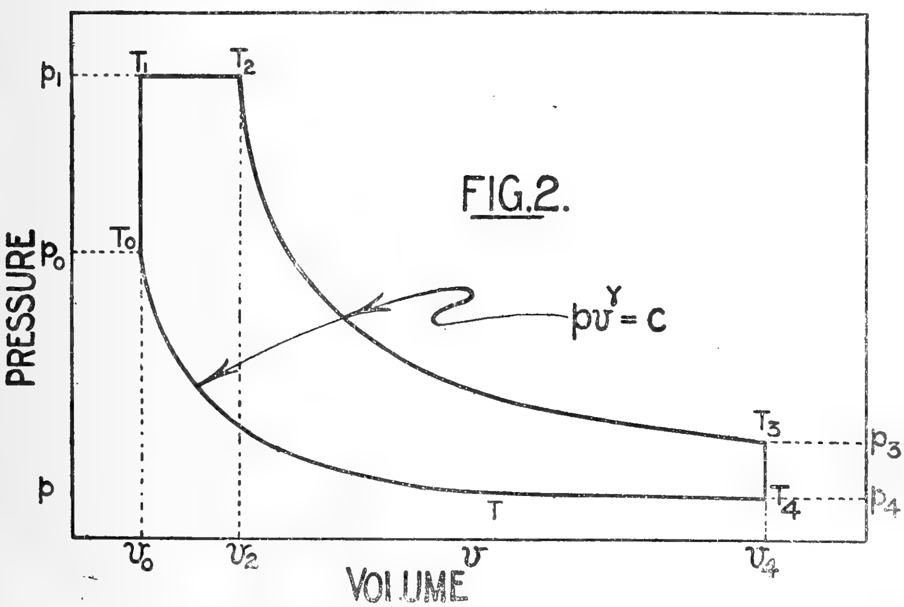


FIG. 2.

Expressing all temperatures in terms of T_4 the following relations result:—

$$T_0 = T_4 r^{n-1}$$

$$T_1 = aT_4 r^{n-1} \quad \left(\text{where } a = \frac{p_1}{p_0}\right)$$

$$T_2 = a\rho T_4 r^{n-1} \quad \left(\text{where } \rho = \frac{v_2}{v_1}\right)$$

$$T_3 = \frac{a\rho^{\delta}}{r^{\gamma-n}} \quad T_4$$

Substituting these values in (3)

$$\eta = 1 - \frac{\dfrac{a\rho^{\delta}}{r^{\delta-1}} - r^{1-n} + \dfrac{\delta - n}{n-1}\left(1 - r^{1-n}\right)}{a - 1 + a\delta(\rho - 1)} \qquad (4)$$

Given pressure limits are evidently conditioned by

$$ar^{n} = \text{constant} = C.$$

Given volume limits imply that r is constant.

Expression (4) now becomes

$$\eta = 1 - \frac{A - \dfrac{\delta - 1}{n-1}\,r + \dfrac{\delta - n}{n-1}\,r^{n}}{B - r^{n}} \qquad (5)$$

where A and B are constants

$$A = \frac{c\rho^{\delta}}{r^{\delta-1}}$$

$$B = c(1 + \delta\overline{\rho - 1})$$

The cycle shown in *Fig.* 2 has already been investigated in a previous article.[3] There it is shown that the efficiency of this cycle is given by an expression of the form

$$\eta = 1 - \frac{A^{1} - \delta r}{B^{1} - r^{\delta}} \qquad (6)$$

where A^1 and B^1 are constants.

The efficiency-compression ratio curves (*i.e.*, η against r) for this second cycle, as derived from equation (6), are shown by the full line curves of *Fig.* 3, for different values of ρ, where also are shown the dotted curves giving the relationship between η and n as expressed by (5).

For the purpose of showing these two sets of curves together in a convenient way, it should be stated that the compression ratio chosen as constant in (5) is taken as 14, a figure integrally proportional to the value of n for adiabatic compression, here assumed to be equal to 1.4. Further, the maximum pressure in both cycles is fixed by the additional assumption that $a = 1$ when $r = 14$ in (6). This limitation may serve at the same time as an indication of the maximum pressures permissible in practice, for if p_4 is the atmospheric pressure, the resulting maximum pressure when $r = 14$ and $n = 1.4$ is in the neighbourhood of 500 lbs. per sq. in. abs. Obviously, another result of the choice made is that the limiting cases of the cycle of *Fig.* 1 when $n = 0$ and 1.4 are also the limiting cases of the cycle of *Fig.* 2 when $r = 1$ and 14. This appears readily from an examination of the graphs in *Fig.* 3 where the dotted and full lines represent the variation

3. *Engineering*, "A New Thermodynamic Cycle," April 9, 1920.

in efficiency with different values of n and r in (5) and (6) respectively.

Several interesting points appear from an examination of these curves. With reference first to the dotted lines it will be observed that in the cases when $\rho = 1.1$, 2 and 3, there is a definite minimum efficiency for each, and that as ρ increases there is a tendency for this minimum to disappear until, as shown for the values $\rho = 9$ and 14 there is no evidence of either a minimum or maximum point. In each of these cases also the efficiency tends to a limit when $n = 1.4$, which limit is also the same (as may easily be verified) as the Diesel engine formula for efficiency, namely,

$$\eta = 1 - \frac{1}{r^{\delta - 1}} \times \frac{\rho^{\delta} - 1}{\delta(\rho - 1)} \quad - \quad - \quad - \quad - \quad (7)$$

It is natural to expect, therefore, that the same limit obtains when $\rho = 1$ in (5), but on plotting the graph it is evident that there is no such limit arrived at by any approximation of n to δ as close as it may be desired to make it. The limiting efficiency of (5) when $\rho = 1$ and $n = 1.4$ instead of being in the neighbourhood of 65.2 per cent. as it is in the limiting case of (7) when $\rho = 1$ and $r = 14$, appears to approach a value in the neighbourhood of 38 per cent. Glancing at the dotted curve for $\rho = 1.1$ it is apparent that, as n approaches the value 1.4 the efficiency increases very rapidly to the limiting value of (7).

The reason for this difference in limiting efficiencies in the two cases when $\rho > 1$ and when $\rho = 1$ is readily understood from the temperature-entropy diagram of *Fig.* 4. Here the cross-shaded portion represents the cycle of *Fig.* 1 when $\rho = 1.0$. In this case as n approaches δ the adiabatic expansion line and the compression line tend to coincide. This also occurs in the limiting cases of the Carnot, Constant Volume and Constant Pressure Cycles, as the amount of heat given per cycle approaches the zero value. This does not mean, however, that the limiting efficiency is the same for the particular cycle under consideration as it is for these. Efficiency on the $T\Phi$ diagram is given by the ratio of areas representing there the work done and the heat given, the nature of which ratio can generally be inferred from an examination of the diagram. It is apparent at once from *Fig.* 4, that as the pv^n line of the cross-shaded area tends to approach the pv^{δ} line, the area approaches to a limit somewhere in the neighbourhood of half that in the Carnot or the Constant Volume or Constant Pressure cycles, while the heat given will tend to become approximately the same in all cases. This means that the efficiency will approach a value somewhere in the neighbourhood of half that of the value of $1-\frac{1}{r^{\delta-1}}$. This explains the approach of the efficiency to a value of 38 per cent. instead of 65.2.

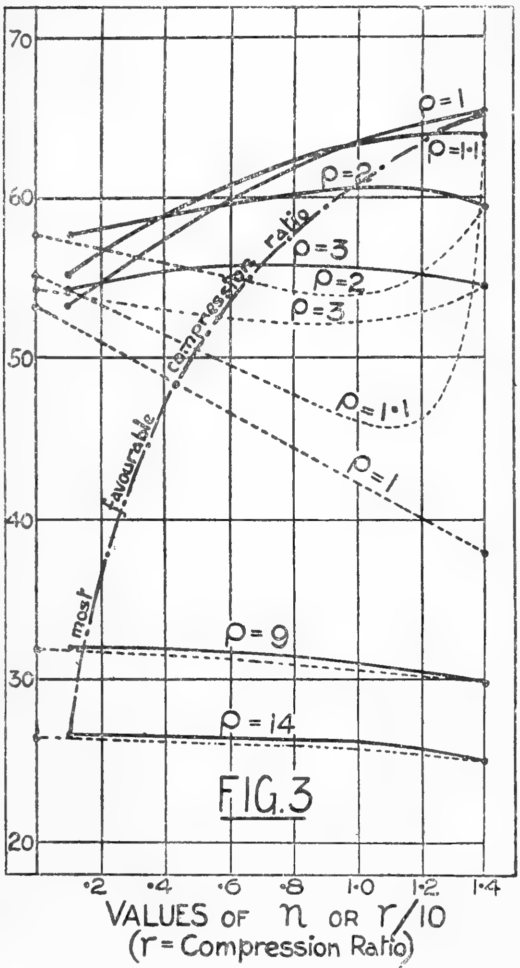


FIG. 3

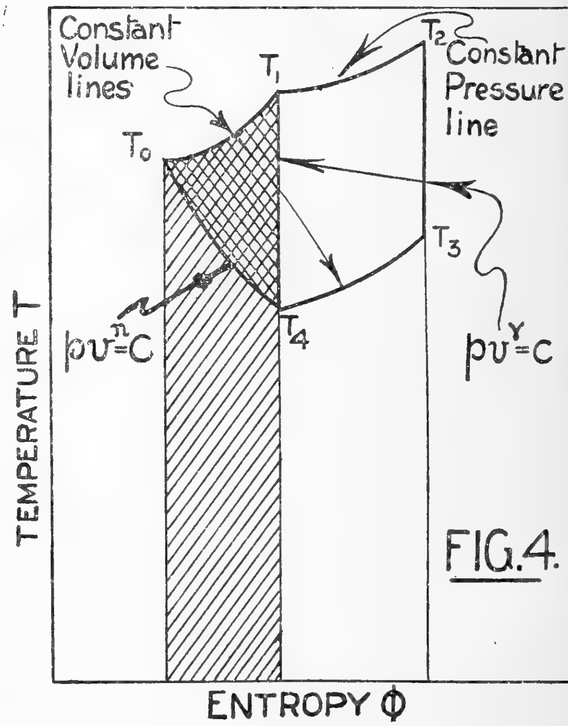


FIG. 4.

If, however, ρ has a value greater than unity (say 1.1), as represented by the complete diagram of *Fig.* 4, then as n approaches δ, the effect of diminution of the shaded area in reducing efficiency becomes negligible, since there always remains the work done and the heat given represented by the corresponding portions of the unshaded area, so that the limit in this case is determined by the ratio of these portions. This ratio is always given by (7) when $\rho > 1$.

These facts at once explain why efficiency generally does diminish in internal combustion engines when "n" is intentionally or otherwise reduced in value, but to the writer's knowledge, it has never been pointed out that this is due to the peculiar nature of this approach of the efficiency to its limiting value when the expansion and compression lines coincide in the manner indicated, *i.e.*, not by *parallel* approach of the lines but by *convergent* approach. The effect of this in reducing efficiency becomes damped more and more as the amount of heat given increases, as appears clearly from the dotted lines of *Fig.* 3. This is also the explanation why, with extra heavy engine loads, efficiency is scarcely, if at all, affected by water injection.

The abrupt change in the character of the graphs (represented by the dotted lines of *Fig.* 3) which is apparent when the curve for any value of ρ as close to unity as may be desired, is compared with the curve for a value of ρ=unity, would appear to indicate that the latter graph should be represented not only by the dotted line shown but also by a vertical line from an efficiency value of 38 per cent. to an efficiency value of 65.2 per cent., when $n=\delta$ or 1.4. Examination of (5), however, shows, as already observed, that this is not the case. The true explanation is that as ρ approximates to unity, that portion of the graph represented by $\frac{d\eta}{dn}$ approaching an infinite value, is really a region of what may be termed "unstable" efficiency, *i.e.*, as ρ approaches unity a very slight change in the value of n results in a large change in the value of the efficiency. When, however, ρ=unity, there is no such unstable portion in the curve.

The above point is, perhaps, rendered more clear by reference to *Fig.* 5. In *Fig.* 3 it will be observed that, in the limit when $\rho=1$ and $n=1.4$, the value of a is unity. In the curves of *Fig.* 5, however, the values of the variables concerned have been so chosen that $a=1.1$ when $n=1.4$, r being taken as 10. The curves shown there for different values of ρ indicate that the limiting case of *Fig.* 3 when $\rho=1$ does not apply here. It is interesting to note therefore that the reason for the theoretical minimum for the "$n\eta$" curves can be traced in every case to the peculiarity of the limiting case of *Fig.* 3.

In *Fig.* 6 the curves showing the relationship between η and ρ are given for different values of n. The interesting point about these is the existence of a maximum efficiency point in each case, the value of ρ at this maximum point increasing as the value of n diminishes.

Referring now to the full lines of *Fig.* 3 giving the relationship between η and the compression ratio r, it is striking to notice that in each line of this series of graphs there is a definite maximum efficiency value and no minimum as in the series just discussed and represented by the dotted lines of the same figure. These maximum efficiency points of these full line curves have already been pointed out in the last article to which reference has been made in this paper. It is raised here again owing to the curious inverse nature of these efficiency curves in relation to those of the cycle of *Fig.* 1. It should be noted, as stated before, that the only difference between the two cycles is that when the fluid is in the state $p_4v_4T_4$, in either case, the state $p_0v_0T_0$ is arrived at in the one case represented by *Fig.* 1, by the same type of polytropic compression throughout the whole of the stroke, while in the other case, represented by *Fig.* 2, the same state $p_0v_0T_0$ is arrived at after two types of polytropic compression, namely, constant pressure compression for the first part of the stroke and then adiabatic compression for the remainder of the stroke.

The full line curves of *Fig.* 3 also show that the value of r, the compression ratio at which maximum efficiency occurs, diminishes as the value of ρ increases. Thus, at a value of ρ=unity, maximum efficiency is obtained when $r=14$. When $\rho=2$, maximum efficiency is derived at a compression ratio $r=10$. For a value $\rho=3$, maximum efficiency occurs when $r=8$ and so on. This obviously falsifies the claim that the Diesel cycle is theoretically the most efficient between given pressure and volume limits. There is, of course, no question of its relatively high efficiency as compared with contemporary engines, but a perusal of Diesel's book, "The Rational Heat Motor," is convincing enough evidence that Diesel himself was too obsessed with the high compression ratio fetish to work the problem out theoretically to its logical conclusion. His primary conception was to adapt the Carnot Cycle to internal combustion principles, and it appears to have required actual experiment to convince him that the problem of engine weight was bound to intervene and require compromise. This led him from constant temperature to constant pressure combustion. Even then he persisted in retaining the operation of rejection of heat at constant temperature, and there again experiment appears to have been necessary to convince him of a fact which theoretical investigation would have revealed. In spite of this, however, Diesel's work appears to have been in large measure the direct cause of the prevailing tendency to rely upon compression ratio as the determining factor in engine efficiency. Many engineers, no doubt, will be scep-

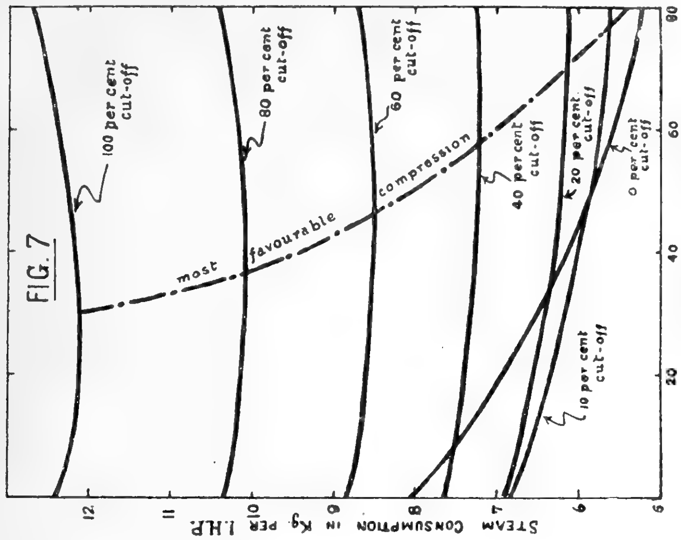


FIG. 7
100 per cent cut-off
80 per cent cut-off
60 per cent cut-off
40 per cent cut-off
20 per cent cut-off
10 per cent cut-off
0 per cent cut-off
most favourable compression
STEAM CONSUMPTION IN Kg. PER I.H.P.
PERCENTAGE COMPRESSION

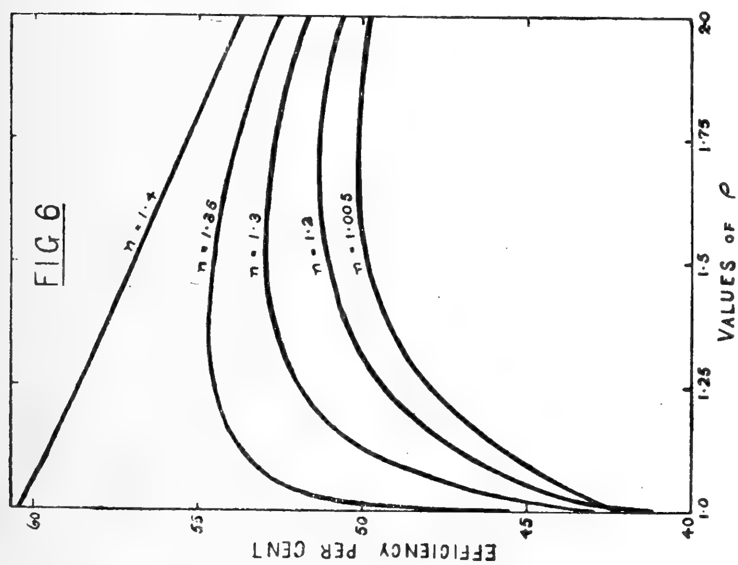


FIG. 6
n = 1·4
n = 1·35
n = 1·3
n = 1·2
n = 1·005
EFFICIENCY PER CENT
VALUES OF ρ

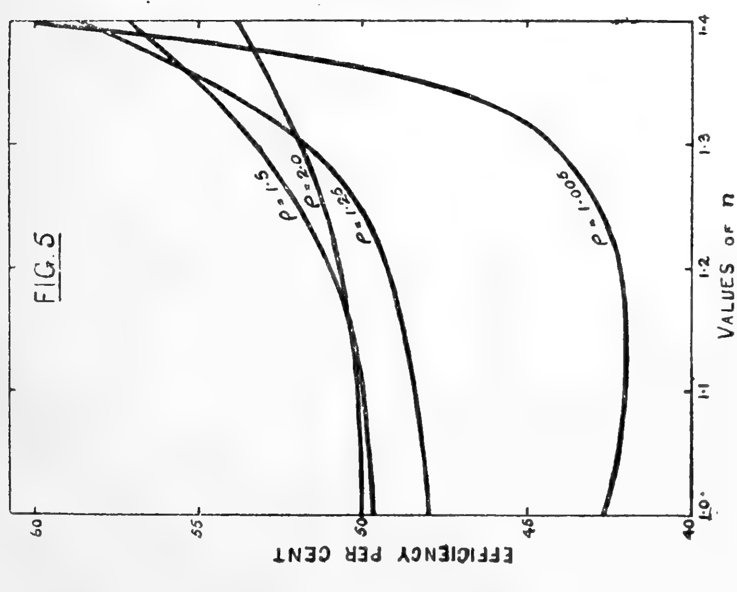


FIG. 5
ρ = 1·5
ρ = 2·0
ρ = 1·25
ρ = 1·005
EFFICIENCY PER CENT
VALUES OF n

tical of any advantage to be derived from any attempt to operate an engine on the maximum efficiency cycle as obtained from formula (6). The writer, however, would quote the following paragraph from Sir Dugald Clerk's book, "The Gas, Petrol and Oil Engine," Vol. 1, in which he says (p. 67) that "if" a cycle "gives a higher efficiency in theory it will do so in practice provided the practical losses do not increase with improved theory." Engineers may judge whether an engine with a given compression ratio will have more or fewer practical losses than another of higher compression ratio. Experience, at least, in this respect, is all in favour of the engine with the lower compression ratio.

It will be observed that in the cycle of *Fig.* 2 the expansion and compression lines tend to coincide by *parallel* approach as r tends to the value 14, so that whether ρ is equal to or greater than unity, the limiting efficiency will always be given by (7). This is clearly borne out by the full lines, as plotted.

Attention may be drawn to the fact that these full line curves indicate the path along which improvement in present-day internal combustion engine efficiencies may be obtained. Reduction of the high compression ratio of the Diesel engine, in the manner indicated in *Fig.* 2, with combustion of fuel at constant volume as well as constant pressure, are the lines along which it appears experiment should be directed in order to determine whether, to the foregoing results theoretically deduced, corresponding practical results can be obtained.

Nothing further remains to be said about these full line graphs except to refer to the chain line which has been drawn through the maximum efficiency point of each of these curves. This has been done for the sake of comparison with some curves drawn for the cycle followed in the well-known Uniflow type of steam engine. The cycle of this engine corresponds closely to that of *Fig.* 2. The writer was only made aware of the existence of these results some considerable time after the deduction of the formulæ leading to the curves of *Fig.* 3, and the surprisingly good agreement he found between his own and the uniflow steam engine curves was naturally gratifying, arguing, as it did, for the practical value of formula (6). The uniflow steam engine curves referred to are given in *Fig.* 7. These are taken from Prof. J. Stumpf's book on "The Uniflow Steam Engine."[4]

Now, the efficiency of the cycle of *Fig.* 2 has been deduced on the assumption that the working fluid is a perfect gas. In

4. Constable and Co., 1912.

the case of the Uniflow engine, the working fluid is practically always superheated steam, and it would appear from the agreement between the curves of *Fig.* 7 and *Fig.* 3 that formula (6), with suitable values for the constants inserted therein, could be applied to this engine and used as a standard of comparison. The equations deduced by Stumpf are much more elaborate and involved (as is usual for efficiency expressions of cycles in which steam is the working fluid) and further require the use of an entropy diagram to determine the efficiency values in each case. Comparing the chain lines of *Figs.* 3 and 7, the agreement is obvious. It should be observed, of course, that the curves of *Fig.* 2 give steam consumption values against percentage compression, so that the minimum steam consumption values of that figure correspond to the maximum efficiency values of *Fig.* 3.

The originators of the Uniflow engine appear to have been to some degree inspired by the *Mechanical* principle involved in the operation of a well-known internal combustion engine known as the Koerting gas engine. Perhaps the Uniflow engine in its turn may be the means of drawing the attention of internal combustion engineers to a *Thermodynamical* principle which offers a chance of improving upon Diesel engine efficiencies.

Manchester Memoirs, Vol. lxv. (1921), *No.* 3

III.—The Work and Discoveries of Joule.

By Sir DUGALD CLERK, K.B.E., D.Sc., LL.D., F.R.S.

FIRST JOULE MEMORIAL LECTURE, *December 14th, 1920.*

The greatest generalisation in the early history of physical science was made late in the seventeenth century by Sir Isaac Newton when he enunciated the laws of motion and deduced from them the existence in space of attraction between planets and the sun. Mechanical science has been built up on Newton's fundamental propositions and discoveries.

The discovery by Joule in the middle of the nineteenth century of the mechanical equivalent of heat and his suggestion and determination of the existence of an absolute zero, together with the adaptation of Carnot's cycle of 1824 to the theory of heat as a mode of motion, provide generalisations of equal importance to Newton's law of gravitation; and from them fundamental thermodynamic laws are deduced—the equivalence of energy in different forms; conservation of energy and dissipation of energy.

Joule's discovery in fact called the modern science of thermodynamics into existence.

It is true that men of the first rank in intellect—Newton, Cavendish, Rumford, Young and Davy—had long before expressed the opinion that heat was not material in its nature, but was a mode of motion; but their opinions, although to some extent supported by experiment, made little impression upon the scientific world; and as late as 1850 we still find most distinguished physicists adhering to the "Caloric" or material theory of heat.

Sir William Thomson, for example, believed in the material theory as late as 1848, as he then declared in a paper read at the Cambridge Philosophical Society :—

> . . . . . " the conversion of heat (or caloric) into mechanical effect is probably impossible, certainly undiscovered. In actual engines for obtaining mechanical effect through the agency of heat we must consequently look for the source of power, not in any absorption or conversion, but merely in a transmission of heat."

May 12th, 1921.

This statement was made by the great physicist a year after his first acquaintance with Joule at the British Association Meeting of 1847 held in Oxford. At the Oxford Meeting Joule gave an account of his determinations of the mechanical equivalent of heat by the friction of fluids. Thomson took part in the discussion, and he stated in 1882 that he then made Joule's acquaintance and that it quickly ripened into a life-long friendship. At the meeting, however, he said that he felt strongly impelled to rise and say that Joule must be wrong, because he knew from Carnot's law that the amount of work obtainable from a given quantity of heat varied with the temperature differences between source and refrigerator. He became convinced later that Joule had discovered an important truth, and that there must be some means of reconciling the laws of Joule and Carnot. It took Kelvin some four years to abandon the errors of the material theory, and he did not abandon that idea till after the mathematical work of Macquorn Rankine in Scotland and Clausius on the Continent had provided the necessary reconciliation between the Joule and Carnot laws by showing that heat is converted into work and accordingly disappears to the extent of the performance of the work, but to do this it requires a certain proportion of the total heat dealt with to be discharged from the engine by conduction at the lowest temperature of the cycle of operations.

Joule and Thomson were agreed as to the difficulty of mentally accepting both laws, and Joule proposed that the Carnot idea should be abandoned. Thomson fortunately was convinced of the essential truth of Carnot, and ultimately the two great laws of thermodynamics were accepted. The first law was Joule's, and stated the existence of a mechanical equivalent of heat. The second law was Carnot's, and stated that between given temperature limits the heat which it was possible to convert into mechanical work varied with the range of the temperature limits. Both laws were determined quantitatively when the absolute zero of temperature was discovered, first by Joule on one train of reasoning and later by Thomson on another. At the time we are discussing—1850—the bare conception of the idea of an absolute zero of temperature was one which was startling in its boldness, and it must have been difficult indeed then to imagine any definite line of proof which could be followed to establish the real existence of such a physical limit. We are so familiar with the existence of high temperatures, vastly transcending the temperatures in which we personally exist, that we can hardly admit a temperature limit on the ascending side; that is, we can hardly think of any given temperature which could not be exceeded under quite conceivable circumstances. We know, for example, that any metal—say, platinum—may be melted if its temperature be sufficiently increased; that a further sufficient increase will convert the liquid metal to the gaseous state, and that the gaseous metal may be heated indefinitely while in that state. We know the behaviour and properties of many substances at high temperatures, and are aware of the strong tendency of all chemical compounds, when highly heated, to split up into the elementary bodies composing them. All this we appreciate, but we find it difficult to see how a point of temperature could be reached when it could be said: this is a physical limiting point on the ascending scale; we may heat a substance up to this temperature but not beyond. It is necessary here to distinguish between a conceivable limit and a practical limit under existing conditions. We may thus place limits, say, to the maximum temperatures of coal gas and air explosions, or the temperatures possible from the electric arc; the limit with coal gas and air depending on one set of conditions and the electric arc upon another set, such as the vaporising point of carbon, and so on. In the same way, at the middle of last century, it would have been considered quite reasonable to suppose that human existence was carried on at an intermediate plane of temperature, and that temperatures might exist as low relatively as our known furnace and combustion temperatures are high. At this time such an idea was quite a reasonable one. It is remarkable that, notwithstanding all the difficulties in the way, Joule in 1847 and Thomson in 1848 proposed temperature scales involving the idea of absolute zero. Joule based his proposal on the dynamic theory of the nature of a gas, and using the centigrade thermometer degrees he concluded that the whole motion of the gas particles or molecules would be exhausted when the gas reached the temperature of $-273°C$. Obviously if heat be caused by the motions of molecules of matter, when the motion ceases the body is totally deprived of heat—it has reached the absolute zero of temperature. As Joule had arrived at the mechanical theory of heat by laborious experiments, begun in 1838, and had fully proved the correctness of the theory and made accurate quantitative determinations of the mechanical value of heat in foot lbs., from 1843 to 1848, he was justified in proposing this limit. Thomson, however, in the next year, reasoning from the Carnot cycle, also attempted to deduce an absolute zero of temperature. Thomson accordingly defined equal temperature differences thus :—

> " Equal temperature differences are to be differences between the temperatures of the source of heat and the refrigerator, when the proportion of work produced from a given quantity of heat is the same."

Thermometers graduated in this way could be treated as instruments based on definite principles and so rendered independent of the particular properties of any material.

Unfortunately the material theory of heat was maintained, and accordingly heat was supposed to pass through the Carnot ideal engine without change; that is, although work was performed by the engine, the refrigerator received the same amount of heat from the engine as was applied at the source. All that was supposed to happen was a fall of a given quantity of heat from a higher temperature to a lower, which was conceived to perform work as water does in a water wheel in falling from a higher to a lower level. This fallacy introduced an important error into the absolute scale, and the definition required that the proportion of work performed by the given quantity of heat was to be the same for each degree. This gave a scale greatly differing from that of mercurial, air, and other thermometers; the degrees defined by it corresponding to larger and larger intervals on the air thermometer as temperature increases. Professor Tait pointed out also that on such a scale of temperature the temperature of a body totally deprived of heat is negative—infinite.

In a Paper published at the Royal Society of Edinburgh in 1851, entitled " On the Dynamical Theory of Heat," Thomson accepted the Joule determinations of the mechanical equivalent of heat and absolute zero, and cleared his mind completely from the errors inherent in the material theory, and he proposed a second absolute thermometric scale deduced from the Carnot cycle as modified by allowing for the disappearance of heat in the process of producing mechanical work. Thomson now defined temperature thus :—

> " The temperatures of two bodies are proportional to the quantities of heat respectively taken in and given out in localities at one temperature and at the other respectively, by a material system subjected to a complete cycle of perfectly reversible thermodynamic operations, and not allowed to part with or take in heat at any other tempera-

ture; or, the absolute values of two temperatures are to one another in proportion of the heat taken in to the heat rejected in a perfect thermodynamic engine, working with a source and refrigerator at the higher and lower temperatures respectively."

This definition led to an absolute scale of temperature which was independent of the substance operated on, and the scale practically coincided with the ordinary air thermometer scale with small deviations due to certain properties of air which were jointly investigated by Joule and Thomson in later years. Thomson, by this method, also determined the absolute zero of temperature as $-273°C.$, and he justified by an accurate deduction Joule's suggestion made in a letter written to Thomson in 1848, that the probable value of Carnot's function is the reciprocal of the absolute temperature as measured on a perfect gas thermometer.

I have taken you through the various steps which the powerful mind of Sir William Thomson had to pass before he gave up the material theory and accepted Joule's dynamical theory with its various deductions, in order to show how great was the genius of Joule in proving the truth step by step by elaborate experiments continued from 1840 to 1849, and how difficult it was even for men of great ability to shake off the errors of the old and accept the truth of the new ideas. If a man of Thomson's great powers of intellect found it difficult to accept Joule's work as late as 1848, how little likely was it that the somewhat vague ideas of Davy and Rumford would ever establish the definite ideas of to-day for which we are indebted mainly to Joule, and also to Carnot, to Macquorn Rankine, Thomson, Clausius, and, to a much smaller extent, to Mayer.

Sir William Thomson recognised this fully in an article on "Heat," written by him and published in the "Encyclopædia Britannica" of 1880, in which he says:—

"Joule's great experiments from 1840 to 1849, creating new provinces of science in the thermodynamics of electricity and magnetism, and electro-chemistry, recalled attention to Davy and Rumford's doctrine regarding the nature of heat, and supplied several fresh proofs each, like Davy's, absolutely in itself complete and cogent, that heat is not a material substance, and each advancing with exact dynamical measurement on the way pointed out by Rumford in his measurements of the quantity of heat generated in a certain time by the action of two horses not urged to overwork themselves. The full conversion of the scientific world to the kinetic theory of heat took place about the middle of the nineteenth century, and was no doubt an immediate consequence of Joule's work, although Rumford and Davy's demonstrative experiments, and the ingenious and penetrating speculations of Mohn, Sequin and Mayer and the experimental thermodynamic measurements of Golding all no doubt contributed to the result."

Lord Kelvin here gave Joule the very highest place among the scientific men who had all contributed something to the establishment of the great science of thermodynamics, but the fact that Joule arrived at the true nature of heat years before Lord Kelvin had abandoned the long-standing error of theory shows that in some respects Joule was Kelvin's intellectual superior, and this alone gives him a place in physical science as a man of a century.

Manchester has been the home of many highly distinguished men; great scientific men, great inventors, and great masters of industry and business, but it is fortunate indeed in its connection with two of the greatest discoverers in the history of the world—Dalton and Joule. A very distinguished professor of your University has recently discussed the whole history of British science on its physical side, and he divides science into epochs, ten landmarks, as he calls them, represented by the names Roger Bacon, Gilbert, Napier, Newton, Dalton, Young, Faraday, Joule, William Thomson and Clerk Maxwell; beginning with Roger Bacon in the thirteenth century and terminating with Clerk Maxwell in the latter part of the nineteenth. That two out of those ten great names should belong to Manchester shows the high position attained by your city in the intellectual life of the Kingdom. Further your Society has been presided over by both great men. Joule was your secretary for years before he became your President. Joule read his first paper before your Society in the year 1841, entitled, "On the Electric Origin of the Heat of Combustion," and was elected a member on the 25th January, 1842. He contributed a long series of papers from 1841 till 1879, a period of thirty-eight years, and he dealt with a great variety of subjects including experimental investigations on the phenomena of the voltaic current, on the determination of the specific heat of bodies, heat and constitution of elastic fluids, notes on mirage, freezing point of thermometers, galvanometers, dip circle, solar photographs, duty of electro-magnetic engines, magnetic storms, polarisation of platinum plates, mercurial air pumps and telescopic oscillations.

In these remarkable Papers and Notes he enunciated many new and important truths. His interests were many and his experimental work was very beautiful; each paper is worthy of a separate lecture but it is only possible for me to deal here with some of his discoveries.

It is necessary to note the nature of Joule's training and the progress of his leading experimental work. Joule's father was a man of wealth and position whose sons were educated at their own homes by tutors. Joule had the advantage of some training, by the great Dalton, in mathematics, but Dalton's illness prevented him instructing his pupil in chemistry. Joule had no college or university training. He was born in the year 1818, and in the year 1838, at nineteen years of age, he began his experimental work by an attempt to improve Sturgeon's electro-magnetic engine. He had no idea as to the nature of mechanical work, and he then saw no objection to perpetual motion. In a letter written in 1839 he stated:—

> "I can hardly doubt that electro-magnetism will ultimately be substituted for steam to propel machinery. If the power of the engine is in proportion to the attractive force of its magnets, and if this attraction is as the square of the electric force, the economy will be in direct ratio of the quantity of electricity, and the cost of working the engine may be reduced *ad infinitum*. It is, however, yet to be determined how far the effect of magnetic electricity may disappoint these expectations."

For three full years Joule experimented with the electro-magnetic engine and measured the work done, the zinc consumed in the battery and the current passing—the current being measured in definite units with a galvanometer, and ascertained the weight of water decomposed electrolytically; he also tested the effect of alterations in the construction and winding of his electro-magnets. He exhausted the whole subject in the most painstaking manner and ultimately he concluded that he had failed irretrievably. In a lecture given by him in the Victoria Gallery, Manchester, on February 16, 1841, he stated:—

> "With my apparatus every pound of zinc consumed in a Groves' battery produced a mechanical force (friction

included) equal to raise a weight of 331,400 lbs. to the height of one ft., when the revolving magnets were moving at 8 ft. per second. Now the duty of the best Cornish steam engine is about 1,500,000 lbs. raised to the height of one ft. by the combustion of one pound of coal, which is equal to five times the extreme duty that I was able to obtain from the electro-magnetic engine by the consumption of a pound of zinc. This consumption is so unfavourable that I confess I almost despair of the success of electro-magnetic attractions as an economical source of power, for although my machine is by no means perfect I do not see how the arrangement of its parts could be improved so as to make the duty of one pound of zinc superior to the duty of the best steam engines per pound of coal; and even if this were attained, the expense of the zinc and exciting fluids of the battery is so great compared with the price of coal as to prevent the ordinary electro-magnetic engine being useful for any but very peculiar purposes."

Joule had reached 22 years of age and he had definitely failed in his original purpose, but his three years of continuous research work in his father's house had given him an education in science which he could not have obtained at that time in any other way.

He continued his investigations on heat, but he did not at once definitely connect heat and mechanical energy; his paper of February 16th, 1841, linked chemical and mechanical effect in definite ratio. He first connected heat with mechanical energy in the beginning of 1843, and by August of the same year he was able to state generally:—

"The quantity of heat capable of increasing the temperature of a pound of water one degree of Fahrenheit's thermometer scale is equal to, and may be converted into, a mechanical force capable of raising 838 lbs. to a perpendicular height of one foot."

As it stands this statement is incorrect; it assumes that heat can be converted into work in the same proportion as is found when work is converted into heat. Joule had proved the accuracy of the latter proposition, but thought that his proof included the former also.

Joule made further determinations by using a paddle rotated in water and other liquids to obtain the heat evolved by the disappearance of mechanical energy, and as a final result of his very numerous experiments he arrived at the mechanical equivalent of heat as 772 ft. lbs. to raise one pound of water through one degree Fahrenheit. This value was used by physicists and engineers for many years.

He began his work in 1838, and for all engineering purposes concluded it in his great paper "On the Mechanical Equivalent of Heat," published in the Philosophical Transactions of the Royal Society in 1850. He had definitely established the mechanical theory of heat, finally dismissed the material theory and also educated himself in scientific research; all within twelve years. In that period he published some twenty-five papers dealing with electro-magnetic engines, the heating in electrical circuits, origin of heat of combustion, specific heat, the rarefaction and condensation of air, mechanical equivalent of heat, electrolytic heat, theory of heat, velocity of sound in gases, and also shooting stars.

The 1850 paper is a perfect model of what a scientific paper should be. It opens with a short historical statement in which the reasoning and experiments of Count Rumford, James Watt, Sir Humphrey Davy, Dulong, Faraday, Grove and Mayer are clearly described in a few words. Joule's Royal Society Paper of 1844 is also mentioned, in which he proved that the absorption and evolution of heat by the rarefaction and condensation of air is proportional to the "force" evolved and absorbed in those operations. Joule also gives the values of the mechanical equivalent which he had obtained prior to 1850 by the different modes of experiment as follows:—

Passing water through narrow tubes 770 ft. lbs.; paddle wheel to produce friction from the agitation of water, sperm oil, and mercury, the respective values were 781.5, 782.1 and 787.6 ft. lbs., all for the heating of one pound of water through one degree Fahrenheit.

The apparatus used for the 1850 investigation is beautifully simple and it is clearly described; it is the method which is illustrated in all the text books.

Three sets of experiments were made: (1) paddle in water, (2) paddle in mercury, and (3) friction of discs rotated against each other. The results obtained were:—

(1) Friction of water	... ...	773.64 ft. lbs
(2) Friction of mercury (*a*)	... ...	773.762 „
„ „ (*b*)	... ...	776.303 „
(3) Friction of cast iron (*a*)	... ...	776.997 „
„ „ „ (*b*)	... ...	774.88 „

Joule gives the following table:—

No. of series.	Material employed.	Equivalent in air.	Equivalent *in vacuo*.	Mean.
1.	Water	773.640	772.692	772.692
2.	Mercury	773.762	772.814	774.083
3.	Mercury	776.303	775.352	
4.	Cast iron	776.997	776.045	774.987
5.	Cast iron	774.880	773.930	

Joule considers the equivalent derived from water to be the most correct, and accordingly he here adopts 772.692 ft. lbs. as the mechanical equivalent of heat.

He concludes this short but epoch-making paper by considering it as demonstrated by the experiments described:—

> 1st. That the quantity of heat produced by the friction of bodies, whether solid or liquid, is always proportional to the quantity of force expended. And 2nd. That the quantity of heat capable of increasing the temperature of a pound of water (weighed *in vacuo*, and taken at between 55° and 60°) by 1° Fahr. requires for its evolution the expenditure of a mechanical force represented by the fall of 772 lbs. through the space of one foot.

The paper is dated June 4th, 1849, and it was read at the Royal Society on June 21st and published in the Philosophical Transactions in 1850.

In the volume 1 of Joule's Scientific Papers, published in 1884, Joule added a note:—

> "A third proposition, suppressed in accordance with the wish of the Committee to whom the paper was referred, stated that friction consisted in the conversion of mechanical power into heat."

Here again we experience the effect of the tenaciously held belief in the material theory of heat as affecting even a Committee of the Royal Society in 1849. Two years later another important paper was read at the Royal Society, the date being June 19, 1851, and the title "On the Air Engine." Here Joule proposed what we should now call a constant pressure air engine which operated by increase of volume by temperature and expanded to atmospheric pressure in the motor cylinder. It includes a pump and a motor cylinder, and heat is applied externally but internal combustion is suggested. The engine is unworkable, but interesting, as it follows a type which was experimentally operated by Sir George Cayley many years before. Ericsson also was building an engine of this type in America which he applied to a ship. Curiously Joule seemed quite unaware of the existence of earlier proposals.

Joule's paper is interesting as showing the ideas of the time as to air motive power as worked out on carefully ascertained data.

Thomson contributes a note to the paper on March 23rd, 1852, in which he calculates the Carnot cycle as applied to an air engine.

At a later date Joule and Thomson worked in conjunction and discovered most important facts on the properties of air and other gases during compression and expansion.

Joule was most accurate and resourceful in the experimental work, while Thomson was brilliant in his mathematical treatment—he rapidly developed the science of thermodynamics in its present form. With Joule he deduced the universal laws as to conservation of energy, and showed notwithstanding that energy was made unavailable by fall to uniform temperature; that is, there was dissipation of available energy although no energy was destroyed.

Osborne Reynolds[1] was of opinion that one reason for Joule's marvellous success in experiments compared with the physicists of the day was due to the fact

> "That he (Joule) possessed the engineer's rather than the philosopher's knowledge of mechanics proved one of the happiest circumstances; as he was thus familiar with the only measure of mechanical action which directly measured the mechanical effect of the physical actions he was about to study."

This is undoubtedly true, but there is a further fact which aided Joule; he followed the typically English method of induction and not deduction.

The deductive method starts with a broad general theory and deduces from that theory the particular facts to be

1. I am greatly indebted to the excellent *Memoir* on Joule by the late Professor Osborne Reynolds, published by The Manchester Literary and Philosophical Society in 1892.

expected; if the theory be in error, then the deductions prove to be incorrect.

The inductive method is supposed to have originated in the mind of Roger Bacon, but it must have existed and been used for many thousands of years before the thirteenth century, because it was the method of trial and discovery of error by experiment, the only method which dispensed with pure theory while developing inventions and contrivances for use in attaining relative comfort and safety. Such applications as fire to produce physical and chemical changes in matter such as are involved in the manufacture of iron, copper, lead, and other metals, or the production of oxides, such as quicklime, the operations of soap-making, glass-making, sulphuric acid production, brewing, distilling, and dyeing, the invention of the wheel, spinning and weaving, have all been developed by the method of trial followed by the correction of errors arrived at experimentally. In fact, by induction many experiments are made and definite knowledge of results obtained even in the presence of erroneous theories. This method enabled progress to be made before true theories were developed. Thus the steam engine had been developed by Newcomen, Smeaton, and James Watt, and applied to locomotion on sea and land as well as to the duties of driving machinery and pumping water, long before any guiding science of heat had come into existence. The engines were mechanically excellent; the fuel economy was good, and they were built in units of thousands of horse-power. Steam power, in fact, revolutionised the social and industrial conditions of the globe; but notwithstanding this great material and engineering success, scientific men, like business men and engineers, were equally in the dark as to the connection between steam motive power and heat. It was seen that motive power of almost any magnitude could be obtained by the agency of heat; but how it was obtained and how much power was necessarily connected with a given quantity of heat was quite unknown. Indeed, as we have seen, even Sir William Thomson as late as 1848 was of opinion that there was no mechanical equivalent of heat. Chemists were no better informed than physicists; they had only recently given up the erroneous and terribly confusing idea of phlogiston as an explanation of heat changes, although Lavoisier's work in France had long proved the conservation of mass of matter throughout such changes. It is true that the fuel consumptions of existing steam engines were known for given outputs of mechanical work. Watt had long ago invented the steam engine indicator and determined the value of the horse-power as 33,000 ft. lbs. per minute. Certain methods of improving economy were evident, and engineers were busily engaged in testing these modes by the slow but sure inductive methods of invention, design, construction and operation in practical work; but in this progress up to the time of Joule they had but little aid from pure science.

The science of thermodynamics did not yet exist. To Joule belongs the credit of bringing it into full existence in a form capable of use by the engineer. Thus, in a paper published in 1843, he states:—

> "In the case of the steam engine, by ascertaining the quantity of heat produced by the combustion of coal, we find out how much of it is converted into mechanical power, and thus come to the conclusion as to how far the steam engine is susceptible of further improvement. Calculations made upon this principle have shown that at least ten times as much power might be produced as is now obtained by the combustion of coal."

At this date, 1843, Joule had fully proved that mechanical work produced heat in a fixed equivalent quantity, and he here assumed that the reverse process may be also followed, by which heat in the same proportion can be transformed into mechanical work. Here he did not appreciate the limitations imposed by nature on the reversed process, and later he recognised that although any heat which disappears in performing mechanical work does so in the Joule equivalent proportion; yet under conditions of limitation of temperature range only a fraction of the total heat can be so converted, the remaining part being passed by conduction to the body at lower temperature.

The ideas of Joule, Macquorn Rankine, Clausius, and Thomson now form so much of the basis of all reasoning upon motive power engines that there is some little danger to the present generation of forgetting what they owe to this great group of distinguished men, but principally to Joule. To appreciate the great advance made it is desirable to consider the position of motive power produced by heat at the middle of the last century. At that time many attempts had been made to displace the steam engine by various forms of air engines. The knowledge of engineers at that time may be found by the consideration of papers read at the Institution of Civil Engineers in the years 1845 and 1853 and the discussion which followed them. Many distinguished men joined in the discussions, including James Stirling, Robert Stephenson, Sir George Cayley, C. W. Siemens, Professor Faraday, and Isambard K. Brunel, the designer of the "Great Eastern."

The 1845 paper was a "Description of Stirling's Improved Air Engine" by James Stirling, M.Inst.C.E., a brother of the inventor, the Rev. Dr. Stirling, a Scottish clergyman, who produced his first regenerative hot air engine in the year 1815. The paper described James Stirling's later development, which consisted in the use of air at a greater density than the atmosphere within the engine which was in operation for some years at the Dundee Foundry Company's Works. Two engines were built of 21 and 45 H.P. respectively, the smaller engine consumed, it was stated, only 2½ lbs. of coal per H.P. hour. This was an extraordinarily good result—about one-half of the most economical steam engine mentioned by Joule. The 1853 meetings were occupied with four papers: (1) "On the use of Heated Air as a Motive Power," by Benjamin Cheverton; (2) "On the Caloric Engine," by Charles Manby; (3) "On the Principle of the Caloric Air Heated Engine," by James Leslie; and (4) "On the Conversion of Heat into Mechanical Effect," by Charles William Siemens, A.M.I.C.E.

The readers of the papers, and those who joined in the discussion, except Siemens, clearly had no information as to Joule's determinations, and they all misunderstood the action of the heat regenerator. Stirling said:—

> "And it thus appears that by applying air successively to a series of bodies regularly increasing in temperature, and moving it alternately from one end of the series to the other, it may be heated and cooled ten times, with an expenditure of caloric which would barely have heated it once, if it had been applied at once, to the hottest body. . . . . . . Nay it is evident that by multiplying the members of the series indefinitely air could be heated and expanded and made to do work at no appreciable expense."

Nearly all those present had no idea that heat disappeared in performing work, and they agreed with Sir William Thomson's 1848 paper, that "the conversion of heat (or caloric) into mechanical effect is practically impossible, certainly undiscovered." That is, that the source of power in heat engines is not in conversion or absorption but merely in transmission of heat. Clearly on this view it was logical to expect an indefinitely great economy if heat loss could be suppressed. C. W. Siemens was the only reader and speaker at the 1853 meeting who fully grasped Joule's idea, and he gave a table showing the theoretical performance of different steam and hot air engines referred to the mechanical equivalent of 770 foot pounds. He states, however, that a perfect heat engine would give a performance of 770 foot pounds per heat unit, which clearly shows that he had not grasped the Carnot cycle in conjunction with Joule's law.

This short discussion of the position of the hot air engine is most useful in proving how much practical men were in need of the work of Joule and Thomson.

It is not surprising that, of all the engineers present, Siemens appeared to be alone in thoroughly grasping the new ideas. Thomson's own conversion from the material theory of heat to the dynamical theory was not complete until 1851, and although he had then succeeded in reconciling the ideas of Joule and Carnot, it is not to be wondered at that engineers two years later had not quite succeeded in grasping the combination of the two laws. This combination, however, supplied engineers with a new and accurate standard of measurement for studying and improving upon their heat engines, and they were by no means slow in grasping the help thus offered them by the abstract scientific man. The broad laws of thermodynamics have placed the theory of the heat engine in a position of certainty, which was much needed. It would be a mistake to assume, however, that even the determination of the mechanical equivalent of heat and the second law of thermodynamics expressed in terms of an absolute thermometric scale had solved all the difficulties of the engineer desiring to determine the efficiency of his heat engines. Joule, Thomson, Rankine, and their great Continental colleagues, it is true, settled once and for all the broad laws of thermodynamics, but the Carnot cycle is a cycle which is, as has been repeatedly shown, an impossible one in practice. Accordingly actual engines have to operate upon imperfect cycles. The theory of these imperfect cycles has been worked out mostly during the last twenty-five years, although Rankine made a beginning in dealing with the theory of the Joule air engine. For the first time he showed the existence of what may be termed a cycle of constant efficiency in the case of the Joule air engine. Assuming constant specific heat for the working fluid, he calculated the efficiency of what we now call a constant-pressure air engine between certain limits of temperature, and he gives the efficiency of the fluid where U=energy exerted and H_1=heat received, and r=ratio of compression and expansion:—

$$\frac{U}{H_1}=1-\left(\frac{1}{r}\right)^{0.408}$$

that is, he indicated in this formula that the thermal efficiency was independent of the maximum temperature as long as that maximum temperature exceeded the temperature of adiabatic compression. He made no statement, however, that this engine was within a certain range independent of the maximum temperature; that was, that increasing maximum temperature did not increase efficiency. Subsequent work has shown that, on a simple assumption, such as constant specific heat of the working fluid, many engine cycles exist of a practicable nature having high theoretical efficiencies where the theoretical efficiency depends on one thing only—the ratio of compression. Some misunderstanding has arisen with regard to these imperfect cycles, and it has even been thought that such imperfect cycles would be contrary to the second law of thermodynamics. Lord Kelvin himself was of this opinion in 1881. I vividly remember a conversation I had with him at the Crown Iron Works, in Glasgow, over the results I had obtained from one of my early gas engines. I had then come to the conclusion that the "Otto" cycle as ordinarily operated was a cycle of constant efficiency, and I explained this to Lord Kelvin. He had not followed such cycles, and his view then was that no such cycle could exist, because he thought it was contrary to the second law of thermodynamics. Some idea of this kind had been held by many scientific men, and had prevented the minute investigation of imperfect cycles of different kinds, because of the feeling that the whole question of efficiency was entirely settled by the nature of the temperature limits; that is, by the maximum and minimum temperatures at the disposal of the engineer. It is true that these values, as has been shown, must always determine the extreme limit of possible efficiencies between certain temperatures, and in cycles of constant efficiency the particular efficiency of the cycle is always less than the efficiency of a Carnot cycle engine working between the same limits of superior and inferior temperature. The investigation, however, of these imperfect cycles is much more difficult than the broad investigation of the general thermodynamic laws, because it requires accurate knowledge of the properties of the working fluid dealt with under conditions rendering observation extremely difficult. The modern internal-combustion motor is the successor to the air engine so fully discussed by eminent engineers of sixty-seven years ago; and the forebodings of even so eminent a man as Faraday as to its ultimate success have proved unfounded. Great difficulties have been encountered and many discrepancies have had to be explained, but a minute study of the nature of the working fluid has rendered it more and more possible to calculate the efficiencies to be expected under practical conditions. At the present time we can deal with almost any cycle or any working fluid with some fair approximation to an accurate result. Much work, however, is required before all problems of the working fluid can be said to be solved with regard to any heat engine. Indeed, it may be said that under modern conditions of the use of steam even the properties of the working fluid—steam—have not yet been completely determined.

Notwithstanding all the perplexities involved in the minute study of the imperfect heat engine cycles, we are in a very different position to-day compared with the engineer of 1853. We know all the broad laws as to the conversion of heat into work or of work into heat; and, numerous as are the problems yet to be solved, we at least profit by the guiding light set out for us by Joule with Kelvin and Rankine.

The science of thermodynamics is thus on one of its sides an explanation of the laws of operation of heat engines already in existence. In the case of the electric light, the dynamo and motor; practice and invention began with the scientific discovery of Faraday of the induction of electric currents by magnets in the year 1831. But it took over thirty years by hundreds of investigators and inventors to develop from Faraday's fundamental facts the mass of knowledge necessary to design and construct great central stations with distributing systems and incandescent lamps and motors required to supply a city with light and power. Faraday's discovery was a necessary step in the progress, but many later steps were required together with a huge expenditure of capital before practical success was ultimately attained. Differing types of workers, such as technical men, inventors and capitalists were all equally required.

In the case of the steam engine science sprang from the reasoning on the facts of practice, and the science of thermodynamics explains the action of great mechanisms brought into effective existence by the work of the engineer and experimenter. Scientific research in physics and chemistry is of two kinds; one kind deals with the nature of the phenomena observed, and endeavours to arrive at some soul-satisfying explanation of the why and wherefore of the particular occurrence; the other endeavours to discover hitherto unknown phenomena. Naturally the earlier scientific investigations dealt with known phenomena, and one type of discovery consisted in determining their laws. So far science has often been able to supply the law, but never the explanation. Many laws are known with accuracy, but all reasoning on the facts leads up to the contradiction which inevitably follows the closer application of thought to theories of gravitation, cohesion, light, electricity, chemical action and life; all appear equally inexplicable.

It is an error, then, to assume, as many scientific men do, that the evolution of a great invention usually follows the course in which the abstract investigator discovers the phenomena and determines the laws and the inventor and designer applies these laws and facts to the practical work. Generally the invention has come into being at a time when the laws of its operation were but vaguely known and the stimulus of the successful practical machine led to its abstract investigation to explain its action. This is most important work, because such investigation supplies data to enable the inventor to reason accurately on the next step of improvement. In my own experience of the past forty years I have been able to apply Joule's discovery to the investigation of the theory of internal-combustion engine cycles of operation, and I have been able in conjunction with others to deduce the laws of imperfect cycles and so to calculate with accuracy the limits of thermal efficiency possible in those important heat motors. After many years of work the internal-combustion engineer is able to determine with confidence the line of advance in the modifications of such engines. In my own time brake thermal efficiencies in gas and oil engines has risen by constant reasoning and experiment from 16 per cent. to 35 per cent. of the total heat supplied to the engine. At the same time the practical experiments made have suggested new lines of investigation to scientific men, from which investigations many new laws have been discovered of equal abstract and technical interest.

The debt of the practical engineer to Joule and his great associates is very real, but it is not the type of debt to which I have already referred. That is, the science of thermodynamics did not supply the fundamental laws from which heat engines were invented and developed. What was true of the steam engine was also true of the hot air engine and the internal-combustion engine; all the known types of heat engine at present in use were invented before the year 1850 and practical experimental examples of both hot air and internal-combustion engines were then in operative existence. Thermodynamics supplied the laws of the conversion of heat into mechanical work by which these engines were governed; it explained the relative perfection of engines already in existence; it did not create these engines. It performed the very important service of dispelling the errors of thought which hindered the future advance of heat engines. Such errors as I have described as to the theory of the regenerator, theory of compression and expansion in all steam and internal combustion engines, held by the most eminent engineers and scientific men so late as from 1845 to 1853, were rendered impossible by the splendid work of Joule, Kelvin, Rankine and their continental colleagues. The knowledge of thermodynamics has thus an increasing effect upon instructed engineers of the present generation. It is quite obvious that, although the origin of heat engines cannot be ascribed to Joule's work, yet the improvement and final development towards a maximum conversion of heat into mechanical work is rendered possible to the engineer of to-day by his great discoveries. Engineers and engine designers are most grateful to Joule and look back on his achievements as those of the utmost intellectual and practical importance.

Joule's service to science and mankind are of even greater value: all intellectual discoveries are of the utmost importance to the race. The highest interest of man is found in the development of the intellect; it is there that consciousness of man differentiates him from the other creatures of the earth. Our knowledge of objective things is, after all, purely subjective, and our belief in the existence of objects external to ourselves gives a vivid interest to the pursuit of knowledge of the real things which we feel exist behind the veil of subjective sensations and impressions. The knowledge called scientific is, after all, but knowledge of the sequences of occurrences as observed through our senses and imagined by our consciousness. Great discoveries such as those of Joule greatly increase our grasp of the sequences of physical nature and enable us to predict to some extent the future development of the world in which we live. Joule, like all great discoverers, aids the race to rise by the development of the intellect.

Without discoverers and inventors we would stagnate and deteriorate; with them we may advance some way yet to the production of a better and happier human society.

I wish to thank your Society for the great honour you have done me by permitting me to pay my tribute to so great a man as Joule, whose work has been so vitally important to mankind both in pure science and in practice.

IV.—Studies in Capillarity.

I. Some General Considerations and a Discussion of Methods for the Measurement of Interfacial Tensions.

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(*Read February* 11*th*, 1921, *at a meeting held jointly with* The Faraday Society.)

The series of experimental studies in capillarity to which this paper forms an introduction owes its immediate origin to the pressing necessity for reliable values for the surface tensions at liquid-gas surfaces, at solid-liquid surfaces, and at solid-gas surfaces. An equal need exists for a knowledge of the temperature coefficients of these quantities, and of the contact-angles of liquids with solids, a need which has grown with, and is further emphasised by the remarkable development during the last generation of colloid chemistry and physics.

The value assigned to a surface tension varies very greatly (see p. 6) with the experimental method employed, and while it is true that much excellent experimental work has been done, it is equally true that much of this work has suffered from a lack of co-ordination, and from a want of appreciation of the dynamical and mathematical principles involved. Indeed a large part of the recent work on surface tension is characterised by an accuracy of experiment which verges on the meticulous, accompanied by vague dynamical argumentation in which writers have been saved from serious mistakes of the hundred-per-cent. order only by a providential cancellation of errors.

Thus, in a recent study[1] of the surface tensions of water and of benzene in which the experimental work is of a very high order, the writers point out that the values of the surface tension of water as measured by the capillary-rise and the ripple method differ by as much as 4 per cent.—the deviation being due mainly to the fact that "the theoretical basis of some of the methods is not sufficiently exact".

Nevertheless, the same writers, in discussing the drop-weight method, define an "ideal" drop as one whose weight is given by the equation

$$W = Mg = 2\pi r T \quad . \quad . \quad . \quad . \quad . \quad \text{(i)}$$

"the weight which the drop from any tip would have if Tate's law were valid". Tate,[2] I fear, never promulgated any such law, but contented himself with a simple statement of the proportionality between the weight of the drop and the radius of the tip from which it falls.

Equation (i), in fact, outrages elementary mechanical principles. It

[1] *Jour. Amer. Chem. Soc.*, **41**, 499 (1919). [2] Tate, *Phil. Mag.*, **27**, 176 (1864).

May 17*th*, 1921.

neglects the pressure-excess inside the drop due to curvature, and it would be far more reasonable to define the ideal drop by the equation :—[1]

$$Mg = \pi r T.$$

The error is a common one, and is to be found in most manuals of physical chemistry, although the correction was given a generation ago by Worthington.[2] Fortunately, one is generally concerned in experimental work with ratios of drop-weights, and the peccant 2 disappears on division.

Again, Coombs and Richards,[3] in a careful determination of the surface tension of water and of benzene, have indulged in what the late Lord Rayleigh termed some "mild reflections on the inadequacy of the help afforded by mathematics," in the elucidation of capillary problems.[4] Their criticism takes a curious form, inasmuch as the canon of acceptance or rejection of a particular approximation appears to depend on whether the approximation does not, or does give impossible values when used outside the range for which the approximation is valid. Such a canon would make very short work of the binomial theorem for fractional indices!

It seems very necessary, therefore, to show exactly what problems have been solved mathematically, under precisely what circumstances the approximations given are valid, and in what problems there is a difference of opinion as to the validity of the solutions that have, from time to time, been propounded.

This apart, I desire here briefly to discuss the various known methods for the measurement of capillary constants, and to consider which of them may most usefully be employed in the measurement of interfacial tensions. There is little need to enlarge on the importance of an *accurate* knowledge of the tension at a liquid-liquid interface—the necessity is known—urgent, and the values of the existing figures, determined as they often are by the aid of stalagmometers, visco-stalagmometers, and other instruments of hybrid derivation and of doubtful accuracy, are open to more than a little suspicion.

At the outset I have mentioned the lack of co-ordination of the existing work. The need for an ordered determination of constants is pressing, and it would seem that much of the careful work already done is in measure wasted, not so much by overlapping, for within limits a certain amount of overlap is all to the good, as by the use of different methods whose relative accuracy has not been sufficiently well estimated, and, in some cases, by lack of appreciation of the help which has undoubtedly been given by mathematics.

Without venturing to lay down cast-iron rules, I here give an outline of a systematic attack on the problem, which would have been carried farther during the last year, had the work not suffered interruption by the heavy demands due to the unprecedented influx of students into this, as into other teaching institutions. Briefly outlined, the scheme of work stands as follows :—

[1] See *e.g.* Poynting and Thomson, "Properties of Matter" (1902), p. 161.
[2] *Proc. Roy. Soc.*, **32**, 362 (1881). [3] *Jour. Amer. Chem. Soc.*, **37**, 1643 (1915).
[4] *Proc. Roy. Soc.* (A), **92**, 184 (1915-16).

(α) General considerations, with a review of those methods which are most likely to prove suitable for the measurement of interfacial tensions.

(β) Improvements in the capillary-rise method.

(γ) An experimental study of the limits of accuracy of Jaeger's method.

(δ) A comparative experimental study of the other principal methods, elucidating the sources of error in, and the consistency of these methods.

(ε) The development of methods suitable for the measurement of
- (i) Interfacial tensions,
- (ii) The surface tensions of substances only obtainable in small quantities, and of substances such as molten metals,
- (iii) Contact angles.

(ζ) The systematic measurement of
- (i) The surface tensions of selected classes of organic compounds, paying special attention to temperature coefficients,
- (ii) Interfacial tensions,
- (iii) Contact-angles of liquids in contact with glass and with other solids.

The present paper deals with the first section of the above scheme, and the paper immediately following describes certain improvements in the capillary-rise method which, without loss of accuracy, considerably simplify its technique.

Much difference of opinion exists concerning the reliability of the "Jaeger" method for the measurement of surface tensions. The method, as is well known, depends on the measurement of the maximum pressure required to release a bubble of air from a small capillary tube plunged vertically into the liquid under observation. Experiments are now in progress in which the extruded bubble is photographed under various pressures; the information thus acquired should serve as a criterion of the reliability of the method.

The Measurement of the Tension in a Liquid-gas Surface.

Turn now to a brief consideration of the value of the various methods that have been proposed, from time to time, for the measurements of surface tensions. Some schematic form of set-out is necessary to avoid confusion, and the accompanying genealogical tree, whose structure explains itself, is perhaps as clear as any.

I do not propose to discuss these various methods at great length; I have, in another paper,[1] attempted some estimate of their relative value, and in a recent number of *Science Progress* [2] a very detailed analysis of the capillary-rise and of the drop-weight method has been given.

[1] Ferguson, *Science Progress*, Jan. 1915, p. 428.
[2] Oct. 1920, p. 223.

Methods for Measuring Surface Tension

- (A) Independent of contact-angle
  - Vibrations
    - (1) Vibrations of drop
    - (2) Waves on jet
    - (3) Ripples
  - Balance methods
    - (4) Pull on ring
    - (5) Tension in film
  - Bubbles and drops
    - (6) Pressure in pendent drop
    - (7) Large bubbles and drops
    - (8) Bubbles and drops (any size)
  - Capillary tubes
    - (9) Sentis' method
    - (10) Jaeger's method
- (B) Dependent on contact-angle
  - Capillary rise
    - (11) Capillary tube
    - (12) Capillary plates:
      - (*a*) parallel
      - (*b*) inclined
    - (13) Single plate
    - (14) Large cylinders
  - Balance methods
    - (15) Wilhelmy's method
    - (16) Pull on sphere
    - (17) Pull on disk
    - (18) Buoyancy method
  - Bubbles and drops
    - (19) Total depth of large bubbles and drops

(20) (Unclassified) Drop-weight method.

Generally speaking, one can say that the methods classified under the grouping (B) should in no case be employed unless one has sound independent evidence that the contact angle is either zero, or so small that its neglect introduces no appreciable error into the observed value of the surface tension.[1]

It is to the methods classified under the heading (A) that we must turn to find our ideal method, and of these (7), (4) and (10) promise very well. From my own experience, I incline to say that any of these three methods will give good results, and Jaeger's method is particularly convenient in practice. The maximum pressure-excess can be very exactly measured, and temperature control is relatively easy. It is not sufficiently clearly realised that the method yields absolute and not comparative values, and a certain suspicion appears to exist that the experimental conditions do not approximate closely enough to a statical state. These doubts I hope to settle by the experiments previously mentioned.

Method (4) too, is very convenient and exact if the conditions of the theory are properly observed. By bending a thin rod into a circle of large radius an anchor ring is formed, and suspended by three threads from a balance pan so that its plane is horizontal. If the ring be allowed to touch the surface of a vessel containing liquid and be then withdrawn, a distinct maximum pull is observed, and the surface tension of the liquid can be accurately calculated in terms of the maximum pull and the dimensions of the ring. The method might with advantage be much more widely used, as the weighings can be made accurately, and temperature control is not too difficult.

Of the methods included under the general heading B, it is worth noting that (12*b*) has recently been recommended as a working practical method.[2] Two vertical plates inclined at a small angle are dipped into the liquid under examination, and the angle between the plates is varied until the surface of the liquid between them coincides with one of a series of confocal hyperbolas drawn on one of the plates.

A simple and rapid way of roughly measuring the surface tension of very small quantities of liquids is indicated by Kiplinger.[3] A short column of the liquid is introduced into a capillary tube of known bore which is then tilted until the meniscus at the lower end becomes plane. The surface tension readily follows from a knowledge of the angle of tilt. The results are uniformly 3 or 4 per cent. too low.

Of the various balance methods classified under (B), I have found the measurement of the surface tension pull on a sphere suspended beneath a balance pan very convenient and sensitive.

If the surface tension pull on such a sphere of radius R is equivalent to a force of mg dynes, then it can be shown that [4]

$$m = 4\pi\rho a^2 \left\{ \mathrm{R} - \frac{\sqrt{a\mathrm{R}}}{3} - \frac{a}{3} \right\},$$

[1] The neglect of a contact angle of 8° introduces a 1 per cent. error into the value of T.

[2] Grummach and Bein, *Zeit. Instrumentenk*, June, 1919, p. 195; *Sci. Abs.* A., **22**, 500, 1919.

[3] *Jour. Amer. Chem. Soc.*, **42**, 472, 1920.

[4] Ferguson, *Phil. Mag.*, Nov. 1913, p. 925.

an equation which can conveniently be solved for a^2 by successive approximations. With a sphere of glass just under 6 inches in diameter ($R = 7{\cdot}321$ cm.), and water as the test liquid, the value of m is about 6·35 gms., and, as far as the weighings are concerned, it is quite easy to obtain T to 1 part in a thousand.

The mean of 17 independent readings on different samples of water gave, on reduction to 15° C,

$$T_{15} = 73{\cdot}45 \pm 0{\cdot}023 \, \frac{\text{dynes}}{\text{cm.}}.$$

It may be useful to give here a table of some of the later values obtained for the surface tension of water. The varying values obtained serve to emphasise the difficulties inherent in the subject. Personally, I am convinced that the most potent factor in producing this variation is the difficulty of preparing a perfectly pure substance (or surface). The exact conditions under which the various mathematical approximations hold good are well known, and, *provided these conditions are fulfilled*, the approximations provided will represent the experimental results with more than sufficient accuracy. But the only satisfactory way of settling this point is to undertake the research outlined under the heading (δ) above.

T_{15}.	Observer.	Method.
73·26	Volkmann	Capillary-rise.
73·46	Domke	Capillary-rise.
73·72	Dorsey	Ripples.
73·45	Hall	Weighing tension in film.
73·76	Sentis	Capillary tubes.
74·22	Watson	Ripples.
73·45	Ferguson	Pull on sphere.
74·30	Pedersen	Waves on jet.
72·78	Bohr	Waves on jet.
74·22	Kalähne	Rippled surface used as diffraction grating.
73·38	Richards and Coombs	Capillary-rise.
73·88	Ferguson	Jaeger's method.
73·55	Brown and Harkins	Capillary-rise.

MATHEMATICAL PRINCIPLES.

The evidence above detailed indicates that a considerable confusion exists as to what problems have been, and what have not been exactly solved; and that where the problem is incapable of exact solution, needless doubts have arisen concerning the value of the approximations given, and the conditions under which the approximations hold good. I propose, therefore, in this section, to devote some little space to a discussion of the more important of these problems, and I hope to show that, even in those cases which are usually considered to require complex analysis, second order corrections may be reached by the aid of very simple mathematics, involving nothing more recondite than a few standard differentiations and integrations.

We shall take it for granted that, across any line of length ds drawn in the surface of liquid there is exerted a tension Tds, whose direction is normal to the line, and in the tangent plane to the surface. The quantity T is called the *Surface Tension* of the liquid, and is reckoned, in C.G.S. units, in dynes per centimetre (or grams per second per second).[1] Further, if R_1 and R_2 are the principal radii of curvature at any point of a curved surface in which there exists a surface tension T, then the pressure excess on one side of the surface over that on the other side is given by

$$p = T\left(\frac{1}{R_1} + \frac{1}{R_2}\right).^{2}$$

This is the well-known equation whose solution has, from time to time, engaged the attention of most of the famous analysts of the nineteenth century. Briefly,[3] we may summarise the results of their work in the statements that (1) an exact solution of the equation in its most general form cannot be attained; (2) that even if we confine ourselves to the case in which the surface is one of revolution we can obtain approximate solutions only in certain special cases; and (3) that *exact* solutions may be found in those cases where one of the principal radii of curvature becomes infinite. This is the case contemplated when a liquid rises (or is depressed) between two parallel plane surfaces held closely together, or when a liquid is in contact with a plane vertical wall.

The cases which come under the heading (2) are of most importance from our point of view, and we shall study, in some little detail, the solution of the equation when the surface is one of revolution about a *vertical* axis. Two special cases concern us most closely—(α) the shape of the capillary surface inside a *small* vertical capillary tube, or, what amounts to the same thing, the shape of the outline of a *small* pendent drop of liquid, and (β) the shape of the capillary surface formed when a *large* bubble of air is imprisoned under the surface of a liquid or when a *large* drop of mercury rests upon a solid surface.

It is of the very first importance that we should attach clear ideas to the terms *large* and *small* contained in the preceding sentence.

Introducing the idea[4] of the "specific cohesion" a^2, we may say that a small capillary tube is one in which $\frac{r^2}{a^2}$ is small compared with unity.

[1] *Not* in dynes—an unfortunately common statement.

[2] For a simple proof, see Poynting and Thomson, "Properties of Matter," Chap. XIV.

[3] The discussion following is restricted to the capillary surface under gravity,

[4] a^2 is *defined* by the identity $a^2 \equiv \frac{T}{g\rho}$ so that a has the dimensions of a length. As is well known, for liquids of *zero* contact angle, a first approximation to T is given by $T = \frac{1}{2}rh\rho g$, where h is the height to which the liquid rises in a capillary tube of radius r. Consequently $2a^2$ is of the order rh. Some writers (*Jour. Amer. Chem. Soc.*, **41**, 520 (1919)) apparently use the equation $2a^2 = rh$ to *define* a^2, and then deduce the identity given above. This is quite incorrect.

Or, since $2a^2 = rh$ very approximately, we may put the statement in equivalent form by saying that $\frac{r}{h}$ shall be small compared with unity. It must be very carefully remembered, therefore, that the smallness of a capillary tube is not an absolute thing, but is relative to the magnitude of the surface tension to be measured.

Similarly, where r is the radius of maximum section of a drop or

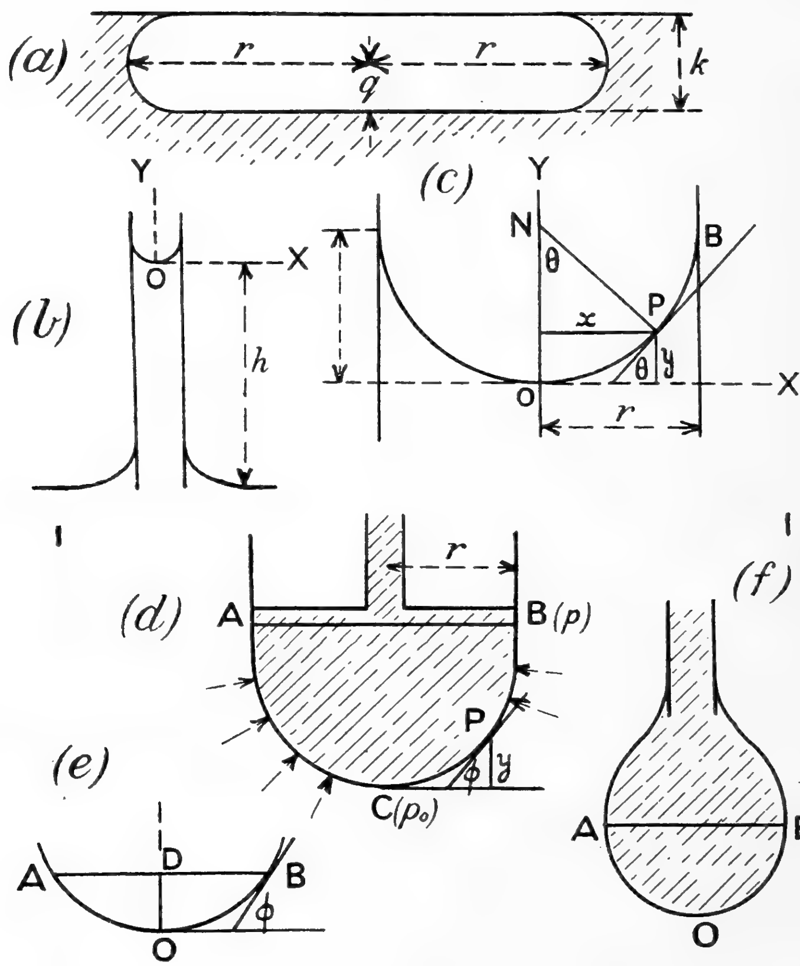

FIG. I.

bubble, the drop is considered to be large when $\frac{a^2}{r^2}$ is small compared with unity. If q be the vertical distance between the plane surface of the drop or bubble and the plane of greatest horizontal section (see Fig. 1 *a*), then, as we shall see, q is of the order of magnitude of a, and the condition implied is that $\frac{q^2}{r^2}$ is small compared with unity.

It must be clearly understood, then, that the equations developed apply, and only apply, when these conditions are fulfilled; and that the failure of the equations outside these limits affords no reason for scepticism as to their reliability inside the limits.

We shall now proceed to develop in as simple a manner as possible the equation of the meridional curve of the surface inside a small vertical capillary tube; the argument will be given for a liquid of zero contact angle—its extension to a liquid of finite contact angle presents no special difficulty.

Let Fig. 1 *b* represent the liquid in its tube, and Fig. 1 *c* an enlarged diagram of the surface. With axes OX and OY as shown the pressure-excess on the two sides of the surface at P is given (i) by $T\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$ and (ii) by $g\rho(y + h)$. Equating these values, we have, where $a^2 \equiv \frac{T}{g\rho}$

$$\frac{1}{R_1} + \frac{1}{R_2} = \frac{y + h}{a^2}.$$

Now R_1 is the radius of curvature at P of the curve AOB, and R_2 is the length PN of the normal at P intercepted by the axis. Hence the above equation becomes [1]

$$\frac{1}{x}\frac{d}{dx}(x \sin \theta) = \frac{y + h}{a^2} \quad . \quad . \quad . \quad . \quad \text{(i)}$$

Innocent as this equation may appear, its exact solution is, apparently, impossible. Approximate solutions have been given by many analysts [2] by more or less complex methods; I shall here attempt to outline a process which will give us the second order correction in a relatively simple way.

In principle the method consists in working out an approximate value for y; this approximate value, substituted in equation (i), now makes it immediately integrable. Integrating, we develop a more accurate value

[1] For (see any text-book on the differential calculus),

$$\frac{1}{R_1} = \frac{d\theta}{ds} = \frac{d\theta}{dx} \cdot \frac{dx}{ds} = \frac{d\theta}{dx} \cos \theta.$$

And, from Fig. 1 *c*

$$\frac{1}{R_2} = \frac{\sin \theta}{x}.$$

Hence

$$\begin{aligned} \frac{1}{R_1} + \frac{1}{R_2} &= \frac{1}{x}\left(x \cos \theta \frac{d\theta}{dx} + \sin \theta\right) \\ &= \frac{1}{x}\left(x \frac{d\,(\sin \theta)}{dx} + \sin \theta \cdot \frac{dx}{dx}\right) \\ &= \frac{1}{x}\frac{d(x \sin \theta)}{dx}. \end{aligned}$$

[2] Laplace, "Mécanique Céleste," Supp. au X^e Livre (1805). Poisson, "Nouvelle Théorie de l'Action Capillaire (1831), Chap. IV. Mathieu, "Théorie de la Capillarité" (1883), Chap. II. Rayleigh, *Proc. Roy. Soc.* (A), **92**, 184 (1915). Lohnstein, *Wied. Ann.*, **54**, 713 (1895).

of y, which is again substituted in equation (i). The process may be repeated again and again, the limit depending mainly on the patience of the operator.

A first approximation to the value of y may be worked out by a method which is a simple modification of that originally used by Laplace. This value is determined quite simply by Mathieu[1] and by Minchin,[2] and the approximate value of y is

$$y = c - \sqrt{c^2 - x^2} + \frac{c^3}{3a^2} \log_e \frac{c + \sqrt{c^2 - x^2}}{2c} \quad . \quad . \quad \text{(ii)}$$

where c is a constant to be determined. In a liquid of zero contact angle, when $x = r$, as at B (Fig. 1 c), $\frac{dy}{dx}$ is infinite. Differentiating (ii) and putting $\frac{dy}{dx} = \infty$ when $x = r$, we see that $c = r$, and therefore

$$y = r - \sqrt{r^2 - x^2} + \frac{r^3}{3a^2} \log_e \frac{r + \sqrt{r^2 - x^2}}{2r} \quad . \quad . \quad \text{(iii)}$$

where r is the radius of the capillary.

Now substitute this value of y in equation (i), and we have

$$a^2 . d(x \sin \theta) = \left(h + r - \sqrt{r^2 - x^2} + \frac{r^3}{3a^2} \log_e \frac{r + \sqrt{r^2 - x^2}}{2r}\right) x dx$$

or, integrating,

$$a^2 x \sin \theta + \text{K} = (h + r)\frac{x^2}{2} - \int x \sqrt{r^2 - x^2} dx + \frac{r^3}{3a^2} \int x \log \frac{r + \sqrt{r^2 - x^2}}{2r} dx.$$

The two integrals are readily evaluated, giving

$$a^2 x \sin \theta + \text{K} = (h + r)\frac{x^2}{2} + \frac{(r^2 - x^2)^{\frac{3}{2}}}{3} + \frac{r^3}{3a^2}\left[\frac{x^2}{2} \log \frac{r + \sqrt{r^2 - x^2}}{2r} + \frac{1}{4}(r - \sqrt{r^2 - x^2})^2\right] \quad \text{(iv)}$$

From Fig. 1 c, we see that x and θ vanish together so that, from (iv), $\text{K} = \frac{r^2}{3}$. Also when $x = r$, $\sin \theta = 1$, and (iv) becomes

$$a^2 r = (h + r)\frac{r^2}{2} - \frac{r^3}{3} + \frac{r^3}{3a^2}\left[\frac{r^2}{2} \log_e \tfrac{1}{2} + \frac{r^2}{4}\right],$$

or

$$2a^2 = rh + \tfrac{1}{3} r^2 - \frac{r^4}{6a^2}(2 \log_e 2 - 1) \quad . \quad . \quad . \quad . \quad \text{(v)}$$

[1] Mathieu, *l.c.*, p. 45.
[2] Minchin, "Hydrostatics" (Oxford, Clarendon Press, 1892), p. 360.

Approximately,

$$2a^2 = rh + \tfrac{1}{3}r^2,$$

and this value, substituted in the small term on the R.H.S. of (v) gives, after a few simple reductions

$$\begin{aligned} 2a^2 &= rh\left[1 + \frac{1}{3}\frac{r}{h} - \frac{r^2}{3h^2}(2\log_e 2 - 1) + \frac{r^3}{9h^3}(2\log_e 2 - 1)\right] \\ &= rh\left(1 + \frac{1}{3}\frac{r}{h} - 0{\cdot}1288\frac{r^2}{h^2} + 0{\cdot}0429\frac{r^3}{h^3}\right) \quad . \quad . \quad . \quad . \quad \text{(vi)} \end{aligned}$$

Now consider the results obtained by more complex methods of analysis. Poisson[1] gives, in effect

$$2a^2 = rh\left(1 + \frac{1}{3}\frac{r}{h} - 0{\cdot}1288\frac{r^2}{h^2}\right).$$

By a very much longer analysis, Rayleigh[2] has obtained a third-order correction, his value being

$$2a^2 = rh\left(1 + \frac{1}{3}\frac{r}{h} - 0{\cdot}1288\frac{r^2}{h^2} + 0{\cdot}1312\frac{r^3}{h^3}\right) \quad . \quad . \quad \text{(vii)}$$

and it will be seen that equation (vi), which only professes to be accurate as far as the term in $\frac{r^2}{h^2}$ inclusive, differs very little numerically from Rayleigh's equation.

An interesting and simple way of approximating to the correction terms was first given, apparently by Desains, who treated the meridional curve as elliptical. One way of arriving at the correction terms on this assumption is given by Mathieu[3] and by Rayleigh,[4] but it can be exhibited in a much more simple and direct way as follows :—

Consider the outline in Fig. 1 (*b* and *c*) as the outline of a semi-ellipse of semi-axes r and b. Then, equating $2\pi r\mathrm{T}$ to the weight of liquid raised (including the weight of the liquid in the meniscus) we have,

$$2\pi r\mathrm{T} = \pi r^2 h\rho g + \tfrac{1}{3}\pi r^2 b\rho g$$

or,

$$2a^2 = rh + \tfrac{1}{3}rb \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(viii)}$$

But, where R is the radius of curvature at the origin O, we have *accurately*

$$2a^2 = \mathrm{R}h,$$

and R, the radius of curvature at the end of the semi-axis minor of an ellipse is equal to $\frac{r^2}{b}$.[5] Hence

$$2a^2 = \frac{r^2}{b}h \text{ or } b = \frac{r^2 h}{2a^2},$$

which value of b, substituted in (viii) gives

$$12a^4 - 6rha^2 - r^3h = 0.$$

[1] "Nouvelle Théorie . . ." (1831), p. 112.
[2] Rayleigh, *l.c.*, p. 189.
[3] Mathieu, *l.c.*, p. 49.
[4] Rayleigh, *l.c.*, p. 190.
[5] See any text-book on the differential calculus.

Solving this as a quadratic in $2a^2$, we obtain

$$2a^2 = \frac{1}{6}\left[3rh + 3rh\left(1 + \frac{4}{3}\frac{r}{h}\right)\right].$$

On expanding the surd, we have finally

$$2a^2 = rh\left(1 + \frac{1}{3}\frac{r}{h} - 0{\cdot}1111\frac{r^2}{h^2} + 0{\cdot}0741\frac{r^3}{h^3}\right) \quad . \quad . \quad \text{(ix)}$$

giving value of a^2 in very close numerical agreement with (vi) and (vii).

The equation

$$2a^2 = rh\left(1 + \frac{1}{3}\frac{r}{h} - 0{\cdot}1288\frac{r^2}{h^2}\right) \quad . \quad . \quad . \quad \text{(x)}$$

is amply accurate for experimental purposes, and may be used with complete confidence in the determination of T for liquids having surface tensions of the order 30 $\frac{\text{dynes}}{\text{cm.}}$, and tubes of 1 mm. (or less) bore. Thus, to fix our ideas, consider a liquid of surface tension 30 $\frac{\text{dynes}}{\text{cm.}}$ and density 0·8 $\frac{\text{gms.}}{\text{c.c.}}$. Such a liquid, if its contact angle were zero, would rise to a height of about 1·5 cm. in a tube of 1 mm. bore. The correcting terms in (x) for this liquid would then be

$$\frac{1}{3}\frac{r}{h} = \frac{1}{3} \times {\cdot}0333 = 0{\cdot}0111, \quad 0{\cdot}13\frac{r^2}{h^2} = 0{\cdot}13 \times {\cdot}00111 = 0{\cdot}0001,$$

and the term in $\frac{r^3}{h^3}$ is quite inappreciable.

Now consider the case of a large drop of liquid sessile on a horizontal surface, or a large bubble of air imprisoned under a sheet of glass. The equations appropriate to such a system are

$$2a^2 = q^2 - \frac{2a^3}{3r}(4 - \sqrt{2}) \quad . \quad . \quad . \quad . \quad . \quad \text{(xi)}$$

and

$$k^2 = 4a^2 \sin^2\frac{\omega}{2} - \frac{8a^3}{3r}\left(1 - \cos^3\frac{\omega}{2}\right) \quad . \quad . \quad \text{(xii)}$$

where r, q, and k have the meanings given by Fig. 1*a*. It is clear that the correcting terms in these equations are of the order $\frac{a}{r}$, and that therefore the size of the bubble or drop should be so chosen that $\frac{a^2}{r^2}$ is negligible in comparison with unity. In the case of water, for example, for which a^2 is about 0·075 sq. cms., a *radius* of $2\frac{1}{2}$ to 3 cm. is the very smallest that can safely be employed. Mr. Langmuir, in some interesting experiments recently carried out on the contact angles of water drops,[1]

[1] *Trans. Faraday Soc.*, XV., June, 1920, p. 62.

has used drops varying from 0·7 to 1·25 cm. in radius, calculating the contact angle from the equation—

$$k^2 = 4a^2 \sin^2 \frac{\omega}{2}$$

in which even the first order correction term of (xii) is neglected. For a drop 1 cm. in radius $\frac{a}{r}$ in the case of water is about 0·27 and $\frac{a^2}{r^2}$ about 0·075, and neither of these quantities can be called small in comparison with unity. It would be far safer to use larger drops, measure both q and k independently, and so obtain the values of a and ω for the actual drop or bubble under investigation. Such a procedure involves no special difficulties, and the necessary observations may be made either photographically or by cathetometer measurements.[1]

I do not propose to discuss here the development of equations (xi) and (xii). In the paper just cited I have given a simple investigation of the problem[2] which is conducted on principles similar to those laid down for the capillary tube problem. The analysis of the anchor ring problem[3] (number 4 in the "genealogical tree") follows much the same lines as the large bubble problem, and the approximations involved are of the same order.

The Measurement of the Tension in a Liquid-Liquid Surface.

This problem is, for the colloid chemist, one of pressing importance, and the attempts made, up to the present, to forward its solution are of very doubtful value. The discussion of the agreement between theory and experiment in the case of the Gibbs-Thomson adsorption formula is pointless unless we have an experimental method which is above suspicion. At present the agreement is apparently considered good if the observed and calculated results differ by less than 100 per cent., while some substances may show adsorption from 20 to 100 times greater than that calculated from the formula.[4] It is sheer waste of time to discuss reasons for these differences so long as the experimental methods are open to suspicion.

The great majority of the figures for interfacial tensions are obtained by some modification of the drop-weight method, in which, instead of finding the weight of a given number of the drops, one determines the number of drops formed by a given quantity of liquid.

Let Fig. 1 *d* represent a drop of liquid of density ρ, pendent, in another liquid of density ρ', from a tube of radius r. The drop is conventionally assumed cylindrical at AB. The equation of equilibrium of the portion ABCA is

$$2\pi r\mathrm{T} + \int_0^r (p_0 - g\rho' y) 2\pi x dx = \left(p + \frac{\mathrm{T}}{r}\right)\pi r^2 + mg,$$

[1] Magie, *Phil. Mag.*, Aug., 1888; Ferguson, *Phil. Mag.*, April, 1913, p. 507.

[2] *L.c.*, pp. 508 *seqq.*

[3] Cantor, *Wied. Ann.*, 47, 399 (1892).

[4] Willows and Hatschek, "Surface Tension and Surface Energy" (*Churchill*, 1919), pp. 51 *seqq.*

where p_0 is the pressure at c in the outer liquid. This leads at once[1] to

$$\pi r\mathrm{T} = mg\left(\frac{\rho - \rho'}{\rho}\right) \quad . \quad . \quad . \quad . \quad (\text{xiii})$$

The theory is at best rough and ready. Moreover, the condition of drop detachment are very complex, and variations, when different pairs of liquids are concerned, are so pronounced, that it is difficult to recommend the drop method even as a comparative one. We shall do better to turn our attention to some of the other methods.

Of these, number (6) in our schematic set-out appeals very strongly. Suppose we form a drop of liquid in such a way that we can measure the vertical distance from any point of the drop surface to each of the free surfaces. We thus know the pressure difference (p) in the equation—

$$p = \mathrm{T}\left(\frac{1}{\mathrm{R}_1} + \frac{1}{\mathrm{R}_2}\right) \quad . \quad . \quad . \quad . \quad (\text{xiv})$$

and it remains to determine R_1 and R_2 at the point in question in order to obtain the value of T. R_1 and R_2 may be measured in several ways.

(1) We may use numerical methods for the solution of the differential equation. The method of Bashforth and Adams[2] consists in "developing the increments of the co-ordinates in series proceeding according to ascending powers of the increment of the quantity chosen as independent variable," and is accurate, but laborious.

Runge[3] has also developed a numerical method for the solution of differential equations, which is, in effect, an elaboration of Simpson's Rule, and he has actually chosen the capillary equation as an example for solution. Picard, Heun, Kutta, and Piaggio, have each devised numerical methods for the solution of differential equations, and an excellent resumé of their work is given in the volume cited below.[4]

(2) We may modify some of the graphic methods for the solution of differential equations. The capillary equation has been treated graphically by Kelvin[5] and by Boys.[6]

(3) As the surface is one of revolution about the y-axis, we may assume an equation of the form—

$$y = ax^2 + bx^4 + cx^6 + \ldots$$

The equation

$$y = ax^2 + bx^4,$$

fits the curve very well for some distance on each side of the vertex. Knowing the co-ordinates of a number of points on the curve, the constants a and b can be calculated by the method of least squares. These being known, the principal radii of curvature at any point can at once be calculated. I have in this way found the value $\mathrm{T}_{11} = 73{\cdot}4$ dyne-cm.$^{-1}$

[1] See also Lewis, *Phil. Mag.*, April, 1908.

[2] "An Attempt to Test the Theories of Capillary Action" (Camb. Univ. Press, 1888).

[3] *Mathematische Annalen*, **46**, 175, 1895.

[4] Piaggio, "Elementary Treatise on Differential Equations," Chap. VIII. (Bell, 1920).

[5] "Popular Lectures and Addresses," vol. i., p. 31.

[6] *Phil. Mag.*, **75**, 36 (1893).

for a water-air surface.[1] At the vertex of the drop, of course, $R_1 = R_2$ and (xiv) takes on the simple form

$$p = \frac{2T}{R}.$$

(4) If the co-ordinates be determined with sufficient accuracy, we may use interpolation formulæ to determine $\frac{dy}{dx}$ and $\frac{d^2y}{dx^2}$ at any point. Knowing these differential coefficients, the values of R_1 and R_2 follow at once.[2]

The above method gives T in terms of the fundamental formula, and should, after a critical estimate has been made of the various methods for evaluating the radii of curvature, yield trustworthy results. It was proposed by me as a possible method for interfacial tensions over eight years ago,[3] and its use has also been recently advocated by Professor Boys.[4]

But cases may arise in which it is not possible to measure the distances to the free surfaces, and it is convenient to have a method by which T may be evaluated from measurements made on the drop alone. This may be accomplished in two ways:—

(α) If oil be floated on the surface of water contained in a large vessel, and a large funnel be inverted and dipped vertically into the oil so that its rim is almost on the interface, a beautiful, flat and stable bubble may be formed by blowing gently into the bubble by means of a spray bulb. This bubble may be photographed and the surface tension evaluated, using equations (xi) and (xii) suitably modified to fit the problem. By photographing an air-bubble blown in this way under water and measuring q and r, I found,[5] from equation (xi) $T_8 = 73{\cdot}7$ dyne-cm.$^{-1}$. No difficulty should be experienced in similarly photographing, say, oil-water bubbles.

(β) With a bubble or drop of *any* size, a knowledge of the Cartesian co-ordinates of a large number of points on the contour enables one to determine T. For the equations of equilibrium of *any* portion of the bubble may be written down in a form which involves the integrals $\int xdy$, $\int x^2dy$ and $\int xydy$. By plotting curves between x and y, x^2 and y, and xy and y, these integrals may be evaluated by means of a planimeter. In this way [6] the equations of equilibrium of a lenticular portion of a small drop of water (the portion ADBOA of Fig. 1 *e*) for which AB was about 4 mm., DO about 1 mm., and the angle ϕ was 45°, yielded a value $T_{11} = 76{\cdot}5$ dyne-cm.$^{-1}$. The value is high, but not unreasonably so, considering the difficulties of the measurement. Better results would probably be obtained if similar measurements were made on the portion ABOA of a drop shaped as in Fig. 1 *f* for which $\phi = 90°$. The method should prove specially useful for the study of the surface tensions of molten metals, alloys, and the like.

[1] Ferguson, *Phil. Mag.*, March, 1912, p. 417.
[2] For an elementary discussion, see Mellor, "Higher Mathematics . . ." (1905), p. 315.
[3] Ferguson, *Phil. Mag.*, March, 1912, p. 430.
[4] Boys, *Jour. Soc. Chem. Ind.*, March, 1920.
[5] Ferguson, *Phil. Mag.*, April, 1913, p. 517.
[6] *Ibid.*, p, 519.

I hope shortly to be able to discuss the results of experiments which will serve to exhibit the capacities of these various methods.

THE SURFACE ENERGY OF SOLIDS.

I do not propose here to do more than indicate one or two ways of accumulating data which may serve to evaluate these important constants.

Measurements of the surface tension in a solid-liquid surface have already been attempted. The solubility of a solid in a given solvent is a function of the dimensions of the solid particles, and changes by a measurable amount when the particles become very small. If s is the solubility for particles of radius r, and s_0 the solubility for "large" particles, then approximately

$$T = \frac{\rho r R\theta}{2} \log_e \frac{s}{s_0}.$$

In this way the surface tension at a barium sulphate-water surface has been found to be of the order 4000 dyne-cm^{-1}.

Similarly the surface tension in a solid-air surface might be measured by atomising and at the same time freezing a liquid. The vapour pressure outside these small particles would differ by a measurable amount from that outside a plane surface; the difference, which could be determined by known methods would serve to measure the surface tension of the solid.

V.—Studies in Capillarity.

II. On a Modification of the Capillary Tube Method for the Measurement of Surface Tensions.

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(*Read February 11th*, 1921, *at a meeting held jointly with* The Faraday Society.)

The determination of surface tensions by the measurement of the rise of a liquid in a capillary tube is more than ordinarily difficult. It is not easy, in the first place, to find a tube of sufficiently uniform cross-section to use with different liquids—some experimenters have spent as much as four months in searching for a uniform piece of capillary tubing.[1] When this is found, the calibrating, cleaning and keeping clean of such a piece of tubing are no small matters. Nor is it easy to measure the height of ascent of the liquid, and to estimate the temperature of the meniscus with the accuracy demanded. And when we remember that, all the measurements having been made with due care, the value obtained is not T, but $T\cos\theta$ it becomes increasingly clear that the convenience of this widely used method is more apparent than real.

The importance of a knowledge of the temperature-coefficient of a surface tension requires special emphasis. Not only does a knowledge of this coefficient enable us to make comparisons between different liquids under comparable temperature conditions, but it also enables us to calculate the critical temperature of an unassociated liquid with considerable accuracy. For the surface tension of such a liquid is expressed very closely, from freezing point to critical temperature, by the equation

$$T = T_0(1 - b\theta)^n$$

where b is accurately the reciprocal of the critical temperature.[2] The exactness with which this equation gives the critical temperature may be judged from the figures given in Table 1 below.

TABLE I.

Substance.	$\theta_c\left(=\frac{1}{b}\right)$.	θ_c Observed.	Difference.
Ether	194·0°	193·8°	+ 0·2°
Benzene	288·0°	288·5°	− 0·5°
Methyl formate	213·0°	214·0°	− 1·0°
Chloro-benzene	358·0°	359·2°	− 1·2°
Methyl butyrate	281·0°	281·3°	− 0·3°
Ethyl formate	235·0°	235·3°	− 0·3°
Propyl formate	265·0°	264·9°	+ 0·1°

[1] Harkins and Brown, *Jour. Amer. Chem. Soc.*, **41**, 503 (1919).
[2] Ferguson, *Phil. Mag.*, Jan. 1916, p. 37.

It is clear, then, that a few measurements of the surface tension of an unassociated liquid at fairly widely separated temperatures will enable us to calculate b and n, and will thus furnish us with a practical method for measuring its critical temperature.

But these measurements demand an accurate knowledge of the temperature of the meniscus—a quantity by no means easy to determine, demanding, as it does, fairly elaborate thermostatic arrangements. Further than that, either expense must be incurred by closing the thermostat with windows of optical glass, or time must be spent in testing such pieces of glass as may be at hand.[1]

The importance of surface tension measurements in modern colloidal work renders it imperative to develop a method which shall be rapid, accurate, and shall not make too heavy a demand on the instrumental equipment of a technical laboratory. It is, we think, the unanimous opinion of workers in this branch of physics that the capillary-rise method is very difficult in practice, and is the reverse of rapid.

Practically all these troubles are swept away if, instead of measuring the rise of the liquid in a narrow tube, *we force the liquid down to the lower end of a tube immersed vertically therein, and measure, on a convenient manometer, the pressure required to effect this.*

Consider the advantages of such an arrangement:—

1. Calibration troubles are completely avoided. It is only necessary to measure, once for all, the bore at the end of a capillary tube of circular cross-section. This end is the position of reference for *all* liquids.

2. The capillary portion of the tube may be quite short, and the tube is consequently much more easily cleaned, and kept clean.

3. The thermostatic arrangements are much simplified. The liquid may be heated electrically, and temperatures taken by means of a fine thermo-couple placed quite close to the end of the capillary.

4. The use of the cathetometer is greatly facilitated. It is far easier to measure the difference of level of the surfaces of a liquid in the limbs of a pressure gauge than to measure the rise in a capillary tube. Moreover, any convenient manometer may be used—a point of importance in a laboratory where appliances are restricted. As is easily seen, if the lower end of the capillary be *just* touching the liquid under observation, and the same liquid be used in the manometer, the difference of level observed will be equal to the height to which the liquid will rise in the capillary tube in the ordinary capillary-rise experiment. Clearly, a gain in sensitiveness is at once obtained by using a light liquid in the manometer. But as said above, any convenient pressure gauge may be used—the micro-manometer devised by Threlfall, the Chattock gauge, the differential liquid manometer,[2] a small receptacle closed by a thin metal disk whose motion may be suitably magnified, or in the absence of these a sloping tube attached to a wide vessel and read by a millimetre scale will give satisfactory results.

[1] Harkins and Brown, *l.c.*, p. 504.

[2] For a description of this simple and interesting instrument, see Barton, "Introduction to the Mechanics of Fluids" (Longmans), p. 193.

The cathetometer is not even necessary to measure the amount by which the capillary is immersed in the liquid. If this distance be determined by attaching a needle to the side of the capillary it is only necessary to form and to caliper a magnified image of the capillary and needle using a good photographic lens.

5. The time of the experiment is appreciably shortened. The accurate determination of a surface tension by the ordinary method is a tedious process, and not one to be adventured upon light-heartedly. In our own case we found that, density determinations apart, an experiment involving 32 separate readings of the cathetometer, could be completed in about $1\frac{1}{2}$ hours. (We usually made 8 determinations of the pressure, and 8 of the distance between the needle-point and the end of the capillary.) With a "naked-eye" manometer, this time could be greatly cut down.

We now pass on to consider the experimental details; a diagrammatic sketch of the apparatus is shown below in Fig. 1:—

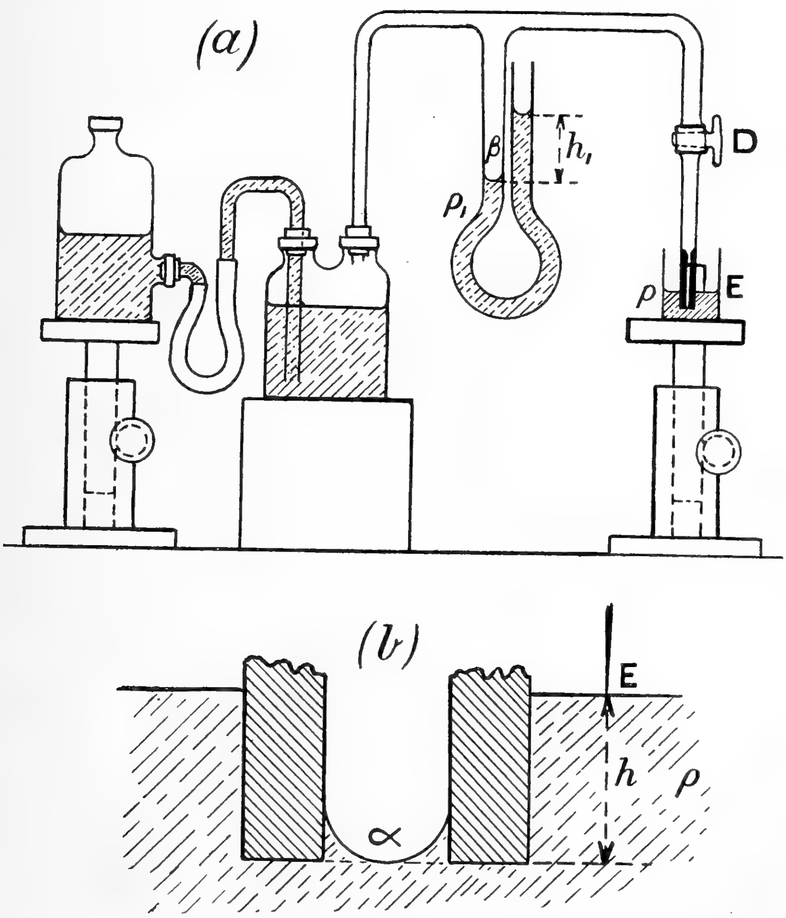

Fig. 1.

The pressure required to force the liquid to the end of the capillary is produced by gently raising or lowering the bottle F by means of a rack and pinion, and the corresponding pressure is read off on the manometer

C which contains a paraffin of specific gravity 0·856 at 15°. The manometer was read by means of a cathetometer, reading to about $\frac{1}{5000}$th of an inch. The capillary tube was cleaned by means of sulphuric acid and bichromate, distilled water, and alcohol, and was dried by blowing through it heated and filtered air. The tube was then fused on to a wider tube just below the stopcock D. (It may here be recorded that the whole of the apparatus was in one piece—all connections being fused together, and no rubber joints admitted at any point of the apparatus. After any one determination the capillary was cut off, cleaned, and re-fused into position.)

The vessel containing the liquid under examination was placed on a movable table and was raised until the surface of the liquid just came into contact with a pointed index E which had been previously firmly fastened to the capillary at a distance h from the end of the tube. This adjustment could be made with great exactness by watching the image of the index point in the liquid surface. By gently raising the bottle F the surface of the liquid in the tube was forced down until the lowest point of the capillary surface, as judged by the eye looking through a low power microscope, was just on a level with the bottom of the capillary tube. The exactness, or rather the *consistency* with which this adjustment may be made is shown by the experimental figures given later. The presence or absence of a constant error in the adjustment was roughly tested by taking readings after adjusting the pressure so that (1) the meniscus just disappeared within the tube, and (2) the meniscus just protruded from the tube; the mean of these pressure readings agreed quite satisfactorily with the "crucial" pressure.

The diameter of the capillary tube was determined by taking the mean of 40 readings (four sets at orientations increasing by 45°). The readings were taken first on the cathetometer used for reading the pressure gauge, and then on a fine dividing engine made by the Cambridge Scientific Instrument Company.[1] The two determinations agreed quite satisfactorily.

The theory of the method is developed as follows:

With the notation of Fig. 1 the pressure at a point α in the air just outside the capillary surface is given by

$$p_\alpha = P + g\rho h + \frac{2T}{R},$$

where P is the atmospheric pressure, T the surface tension, and R the *radius of curvature* at the vertex of the meniscus. But

$$p_\alpha = p_\beta \text{ and } p_\beta = P + g\rho_1 h_1$$

giving

$$\frac{2T}{R} = g(\rho_1 h_1 - \rho h) \quad . \quad . \quad . \quad . \quad \text{(ii)}$$

Now writing $a^2 \equiv \frac{T}{g\rho}$, we know that the height to which such a liquid will rise in a capillary of radius r is, for a liquid of zero contact angle

$$2a^2 = rh_2\left(1 + \frac{1}{3}\frac{r}{h_2} - 0{\cdot}1288\frac{r^2}{h_2^2}\right) \quad . \quad . \quad . \quad . \quad \text{(iii)}$$

[1] With cathetometer, $d = 0{\cdot}0663$ cm. With dividing engine $d = 0{\cdot}06634$ cm.

But we have, accurately

$$2a^2 = Rh_2 \quad . \quad . \quad . \quad . \quad . \quad (iv)$$

and therefore comparing (iii) and (iv)

$$R = r\left(1 + \frac{1}{3}\frac{r}{h_2} - 0{\cdot}1288\frac{r^2}{h^2_2}\right) \quad . \quad . \quad . \quad (v)$$

We have from (iii) to a first approximation

$$h_2 = \frac{2a^2}{r},$$

and to a second approximation

$$h_2 = \frac{2a^2 - \frac{1}{3}r^2}{r}$$

or

$$\frac{1}{h_2} = \frac{r}{2a^2}\left(1 + \frac{r^2}{6a^2}\right).$$

Substituting the exacter value in the second term on the R.H.S. of (v) and the more approximate value in the third term we obtain, after a little reduction

$$R = r\left(1 + \frac{r^2}{6a^2} - 0{\cdot}0044\frac{r^4}{a^4}\right),$$

or, quite accurately enough for our purpose

$$R = r\left(1 + \frac{r^2}{6a^2}\right) \quad . \quad . \quad . \quad . \quad . \quad (vi)$$

Substituting this value of r in equation (ii), expanding and neglecting terms of order higher than $\frac{r^2}{a^2}$, we have finally

$$T = g\frac{r}{2}(\rho_1 h_1 - \rho h) + g\frac{\rho r^2}{6} \quad . \quad . \quad . \quad (vii)$$

as the working equation from which to calculate the surface tension.

The cathetometer used by us was constructed to read in inches. In our case, therefore, equation (vii) takes the form

$$T = gr \times 1{\cdot}27(\rho_1 h_1 - \rho h) + \frac{g\rho r^2}{6}$$

$$= A(\rho_1 h_1 - \rho h) + \frac{g\rho r^2}{6} \quad . \quad . \quad . \quad . \quad (viii)$$

where densities are measured in $\frac{\text{gm.}}{\text{c.c.}}$; r is measured in *cm.*, and h_1 and h in *inches.*

With one of our tubes, $r = 0{\cdot}03317$ cm., and consequently

$$\log A = 1{\cdot}6162.$$

The table immediately following gives the figures obtained in a determination of the surface tension of benzene.

TABLE II.—(BENZENE).

$\theta = 15{\cdot}5^\circ$ C. $\rho_1 = 0{\cdot}8555$. $\rho = 0{\cdot}8837$. log A = 1·6162.

Manometer Readings.			Readings for Immersion of Tube.		
Open Limb.	Closed Limb.	Difference = h_1.	Needle Point.	End of Tube.	Difference = h.
ins.	ins.	ins.	ins.	ins.	ins.
7·658	6·739	0·919	2·266	2·181	0·085
7·657	6·738	0·919	2·267	2·181	0·086
7·658	6·736	0·922	2·268	2·181	0·087
7·658	6·738	0·920	2·269	2·183	0·086
7·658	6·736	0·922	2·268	2·180	0·088
7·658	6·738	0·920	2·258	2·173	0·085
7·659	6·736	0·923	2·258	2·170	0·088
7·659	6·737	0·922	2·257	2·171	0·086
	Mean h_1 =	0·921		Mean h =	0·0864

Hence $\rho_1 h_1 - \rho h = 0{\cdot}7882 - 0{\cdot}0763 = 0{\cdot}7119$.
And from (viii)

$$T_{15\cdot5} = A \times 0{\cdot}7119 + 0{\cdot}16 = 29{\cdot}58 \text{ dyne-cm}^{-1}.$$

The relation between surface tension and temperature in the case of benzene is given by

$$\begin{aligned} T_\theta &= T_o\,(1 - b\theta)^n \\ &= T_o\,(1 - nb\theta) \end{aligned}$$

for small variations in the temperature, where we may take $n = 1{\cdot}21$,

TABLE III.—(TOLUENE).

$\theta = 15{\cdot}0^\circ$ C. $\rho_1 = 0{\cdot}8559$. $\rho = 0{\cdot}8715$. Log A = 1·6162.

Manometer Readings.			Readings for Immersion of Tube.		
Open Limb.	Closed Limb.	Difference = h_1.	Needle Point.	End of Tube.	Difference = h.
ins.	ins.	ins.	ins.	ins.	ins.
8·432	7·561	0·871	2·636	2·595	0·041
8·430	7·562	0·868	2·636	2·594	0·042
8·430	7·563	0·867	2·634	2·596	0·038
8·430	7·564	0·866	2·635	2·595	0·040
8·430	7·565	0·865	2·637	2·597	0·040
8·428	7·566	0·862	2·635	2·595	0·040
8·429	7·567	0·862	2·636	2·597	0·039
8·443	7·579	0·864	2·636	2·594	0·042
	Mean h_1 =	0·8656		Mean h =	0·0402

$\rho_1 h_1 - \rho h = 0{\cdot}7400 - 0{\cdot}0350 = 0{\cdot}7050$.
$T_{15} = A \times 0{\cdot}7050 + 0{\cdot}16 = 29{\cdot}13 + 0{\cdot}16 = 29{\cdot}29$ dyne-cm.$^{-1}$.

$b = \frac{1}{288}$, and consequently $nb = 0{\cdot}00420$. Hence, we may write, very approximately

$$T_{15} = T_t\{1 - nb(15 - \theta)\} \quad . \quad . \quad . \quad . \quad . \quad \text{(ix)}$$

giving a change in the surface tension of about 0·14 dynes per cm. per degree.

From the above experiment, we have, with this value of the temperature coefficient

$$T_{15} = 29{\cdot}65 \text{ dyne-cm.}^{-1}.$$

In Table III. above is given a similar set of readings obtained with toluene.

There is no need to give details of all the readings for the remaining experiments ; Table IV. below gives a conspectus of the results obtained.

TABLE IV.

θ.	ρ_1.	h_1.	ρ.	h.	T_θ.	T_{15}.
BENZENE.						
14·4°	0·8551	0·9257	0·8832	0·0900	29·59	29·73
16·1°	0·8562	0·8841	0·8850	0·0357	30·13	30·05
15·5°	0·8555	0·9210	0·8837	0·0864	29·58	29·65
16·0°	0·8552	0·8903	0·8830	0·0590	29·46	29·60
14·8°	0·8559	0·9024	0·8843	0·0530	29·98	29·95
11·0°	0·8585	1·0932	0·8885	0·0488	30·49	* 29·93
TOLUENE.						
15·0°	0·8559	0·8656	0·8715	0·0402	29·29	29·29
16·0°	0·8552	0·8706	0·8704	0·0524	29·05	29·17
METHYL PROPIONATE.						
15·5°	0·8555	0·7699	0·922	0·0342	26·09	—
11·1°	0·8584	1·0280	0·926	0·1241	* 26·31	—

(The starred results were obtained using a new tube for which $r = 0{\cdot}02724$ cm., and therefore $\log A = 1{\cdot}5307$.)

The production of authoritative figures for the surface tensions of these compounds forms no essential part of this paper ; our main object is to show that the very simple modification proposed removes the chief technical difficulties that beset the capillary-rise method, and that the method does effect this object is almost *a priori* evident. But the discussion of one or two points connected with the above figures will, we think, be of use.

Our experience of benzene has convinced us that this liquid is, for a standard liquid, more than a little treacherous. The six values for T_{15} given above represent but a small fraction of our experimental figures, which, however, group themselves into two classes—one set giving a value of T_{15} of about $29{\cdot}6 \frac{\text{dynes}}{\text{cm.}}$, the other about $29{\cdot}9 \frac{\text{dynes}}{\text{cm.}}$. This latter figure is the value which we generally obtained after performing all the usual rites associated with the purification of benzene. It was only when, in addition, we made several fractional crystallisations of the specimen, and then *immediately* determined the surface tension, that the lower figures were obtained. On allowing the benzene to stand for a few days its surface tension reverted to the higher value.

Whatever be the apparatus employed for the determination of surface tensions, it is clearly advantageous to have at hand a standard liquid which can be used to test the apparatus. We ourselves feel that benzene is far from being the ideal liquid; for it in several respects falls short of such a standard, which should

(i) be easily prepared;
(ii) be easily purified;
(iii) be non-hygroscopic;
(iv) not be liable (like water) to surface contamination;
(v) not attack glass.

In Table IV. above, the first, third, and fifth results were in each case taken immediately after three fractional crystallisations of different specimens of purified benzene. The mean of these gives

$$T_{15} = 29{\cdot}66 \ \frac{\text{dynes}}{\text{cm.}}.$$

In Table V. below are given a few of the results obtained by other experimenters.

TABLE V.

Experimenter.	Method.	T_{15}.
Volkmann	Capillary rise	29·51
Harkins and Brown	,, ,,	29·59
Ramsay and Aston	,, ,,	28·68
Renard and Guye	,, ,,	28·45
Richards and Coombs	,, ,,	29·61
Ferguson	Jaeger's method	29·65
Feustel	,, ,,	30·9

It seems then that, with the exception of Renard and Guye's value,[1] the value we have obtained is in very close agreement with the values given by the ordinary technique of the capillary rise method. The latest and most careful experiments are those of Harkins and Brown, and of Richards and Coombs, and our mean value agrees with theirs to about 1 part in 500.

These experiments were carried out in the Physical Laboratories of the Manchester College of Technology, and it is our pleasant duty to thank Professor Gee for the assistance which he has given us, and for the facilities which he has placed at our disposal.

College of Technology,
Manchester.

December, 1920.

[1] Ramsay and Aston's value is for the surface tension of benzene in contact with its saturated vapour.

A General Discussion in Capillarity and Surface Tension followed the reading of these papers. The Discussion is published in the TRANSACTIONS OF THE FARADAY SOCIETY, Vol. xvii., part 1, 1921.

VI.—Some Chapters from the History of English Spelling and the Need of a New Chapter.

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(Read March 8th, 1921. Received for publication May 24th, 1921.)

The English Language is spoken by over 200 million people. Its widespread use is not so much due to its inherent virtues as to the enterprise of our ancestors who went abroad and peopled a great part of the American Continent, the great islands of Australia and New Zealand and other colonies. The language itself has many virtues and many faults. It has a very simple grammar, and the conjugation of most of the verbs is of the simplest kind. Indeed, we may say that English is a conspicuous example of the fact that conjugation by means of complicated suffixes is entirely unnecessary, the only requirements being a few auxiliary verbs and a few simple suffixes to form the past tense and the participles. On the other hand, while we have demonstrated this important principle we have neglected wholly to take advantage of it, for many of our common verbs have conjugations of the most shocking irregularity. Another advantage in our grammar is its freedom from meaningless genders and from the agreement of the adjective with the noun. These must seem blessings to foreigners studying our language. One of our greatest virtues is the enormous choice of words for the expression of the finest gradation of thought. We have a great supply of monosyllables by which an extensive connotation can be expressed in a small fraction of a second. On the other hand, we have a good choice of long words from which we can construct great undulating sentences such as Milton and Burke revelled in. One very serious defect in our language is the number of words which are spelt alike but which have entirely different meanings.

But by far the greatest defect in our language is its spelling. It has been said by one of our greatest philologists: "Considered as a representation of the sounds of the spoken language, the present English orthography is one of the worst in existence. Almost every sound is expressed in several different ways. . . . ."

June 24th, 1921.

Now we find among educated people a prevailing idea that this irregular spelling is in some way justifiable. Many think that the exact spelling of a word as we now have it connects it in some mysterious way with its past, and that to alter a single letter would be to commit an unforgivable sin against the traditions of our race. To spell scythe without a "c," for instance, is not only (in their opinion) to show ourselves blind to the beauties of our language and the glories of our past, but to put ourselves on the level with the most vulgar hooligan.

This belief in the sacredness of spelling is the outcome of our education under the direction of masters and mistresses[1] of limited outlook. We can all remember the religious rite known as a dictation lesson. A long file of boys or girls take their places around the high priest, who reads from a book passages specially chosen on account of the difficulty of the spelling or the double meaning of the words. After the oration comes the examination, and woeful disgrace to any novice who shall have fallen into one of the pitfalls. It is that feeling of disgrace which our teachers tried to make us feel in those early days that haunts us through life and gives us such a respect for the sacredness of spelling. In fact, the subject of orthography is such a big one in our schools, and such a difficult one, that many schoolmasters to-day consider that if they have succeeded in teaching their scholars to spell really well they have almost discharged their whole duty, even if the other knowledge imparted is of the most meagre character. We know people of so-called culture whose fine knowledge of English spelling looms so large in the make up of their education that they have little else to differentiate them from persons of little education. It is this aristocracy of English orthography that is so opposed to any change. The thought is perhaps not expressed, but it is nevertheless there in the background. "What! take away from me my spelling? Why, what should I have left!" And so it is necessary to find all sorts of justifications for the spelling as it is,—anything to satisfy the conscience and keep the old system alive.

The main object of this paper is to strike at the root of this belief in the sacredness of our present spelling. I hope to demonstrate that the words that are difficult to spell are wrong. Wrong, for the most part, for two reasons: first, because in most of them the irregular spelling

1. It is a good sign that many masters and mistresses are now in favour of spelling reform.

does not give a correct indication of the origin of the word (even if it were desirable to preserve this feature in our spelling); and secondly, because they offend against the true ideal of English spelling as striven after by the great writers of the past.

If anyone suspects me of an unwarranted attack upon the sacredness of English spelling I would advise him to read the preface to Dr. Johnson's Dictionary written in 1755. Dr. Johnson there admits that there was really no authoritative way of writing many of the words, and that the greatest diversity of spelling existed among educated people. There had been several dictionaries before Johnson's, notably Cawdrey's "Table Alphabetical of Hard Words," 1604, and Bailey's "Etymological English Dictionary," 1721; but people in those days had not acquired the habit of looking upon the dictionary as an authority. The great mass of Johnson's Dictionary and its apparent show of scholarship gave people a respect for it that it really never deserved or even claimed. If Dr. Johnson had been a man of wider vision, he would have realised that the essential principle of true English spelling is conformity to sound; and in choosing between the dozens of alternative spellings which were open to him at that time he would have chosen the spelling that most nearly represented the pronunciation most generally accepted as correct. Had he done that, he would have been on firm ground and would have done a great and useful piece of work; but he chose rather the position of the pedant who likes to air his knowledge or supposed knowledge of the origin of words, and, as a consequence, he perpetuated a large number of fanciful and altogether erroneous spellings that had sprung up in a very fanciful period of English Literature. The one redeeming feature of his book is the Preface, in which he admits that his judgment may have been wrong. It was wrong, but people did not read the preface. The schools set up the book as an authority. The learned man, in their eyes, was the man who knew how Dr. Johnson spelt a word. The ignorant man was he who did not know that very tricky and elusive spelling. So the authority of the fetish grew, until in our time we may say that there is a curtain hung up which hides from us the history of the spelling of our words. On that curtain are inscribed in black letters hundreds of words exhibiting the most absurd inconsistencies and want of scholarship, and we are told that that is how we must spell the words, or be relegated in disgrace to the class "uneducated."

I propose to draw aside the curtain that we may have a peep at old English spelling as it was before Dr. Johnson petrified it. I shall ask you to drag down the curtain and burn it, not merely as a useless drapery but as a most disgraceful imposition, which has cost us untold millions to maintain and which has been and is to-day the greatest impediment in our educational system.

The root principle in English spelling (as indeed in all European spelling) is phonetic: to represent consistently the spoken word by written signs. When teaching a child to read, this is one of the first principles that we try to inculcate.

The early English writers followed the principle very much more closely than we do to-day. They laboured, however, under very great difficulties,—difficulties very much the same that beset us to-day.

Early difficulties in Phonetics.

While certain of the consonants, such as B, P, and T, stood for perfectly definite sounds, there were others which stood for more than one sound; and this necessarily led to some confusion. The letter C had two distinct origins and two distinct sounds. One of the C's came from Latin with the bulk of the other letters. In that language it was used instead of K, which was missing from the alphabet. In late Latin the sound of C changed before the vowels *e* and *i*; in old French it was sounded like S. The Norman French brought this soft C into our language, and so we have two; and to this day people don't know which is which. Many of the early writers, in order to avoid confusion, used K for the sound of K, but continued to use a C in words of French origin containing that letter.

The letter G not only had the hard sound as in "get" and the soft sound of J but did duty for two other sounds as well.

Similarly F and H had varying values.

But the main difficulty was with the vowel sounds. We have a large number of vowel sounds and only five or six letters to represent them. Attempts were made by the use of digraphs (combinations of vowel letters) to get over the difficulty, but there was never any agreement as to the sound denoted by each digraph. If in the thirteenth century there had been founded an Academy with authority to decide on the particular symbol to be used for each sound, all would have been well; but there was no such Academy and so each writer had to make the best use of the symbols that he had.

One very sensible thing the early English writers did. The Romans had no sign for the sound of "th" in "thing," so the old English writers took the symbol þ (called "thorn") from the runic alphabet to represent this sound. Further, some of them used the symbol ð for the other "th" sound as in "breathe."

That the intention of the early English writers was to spell phonetically is sufficiently evident from an examination of their writings: indeed, the writer Orm elaborated a perfect phonetic system by which the pronunciation of the vowels was completely indicated by the spelling.

A very interesting example of early orthography is found in the Old English song "Sumer is icumen in," which is reproduced here for the benefit of those who are not familiar with it:—

SUMER IS ICUMEN IN.

(About 1250.)

Sumer is icumen in,
 Lhude sing cuccu!
Groweth sed, and bloweth med,
 And springth the wude nu.
 Sing cuccu!

Awe bleteth after lomb,
 Lhouth after calve cu;
Bulluc sterteth, bucke verteth,
 Murie sing cuccu!

Cuccu, cuccu, wel singes thu, cuccu:
 Ne swike thu naver nu.
Sing cuccu, nu, sing cuccu,
 Sing cuccu, sing cuccu, nu!

(Lhude=loud; Awe=ewe; Lhouth=loweth; Sterteth=leaps; Swike=cease; Murie=merry.)

Allowing for some change in the pronunciation of the vowels, the spelling is much superior to what we have to-day.

Chaucer's spelling was more nearly phonetic than ours to-day. It is true that a great number of French words were introduced into English in his time, and that the French spelling was preserved, although it was not phonetic from our point of view. It is interesting to note that Chaucer's method of writing vowels, while more consistent[2] in itself, was not the same as our method; for instance, long O (as in host, ghost, post) was often written OO by him (hoost, goost, poost). Similarly, the long sound of E (as in meat, seen, clean) was written often by him as in mete, sene, clene. A few lines from "The Canterbury Tales" will illustrate a number of interesting points in this connection. We have, for instance, the words mete, depe, kepe, clene, sene, grece, semely, speken, wepe. Chaucer's metre shows that the final *e* was very often silent.

At mete wel ytaught was she withalle,
She leet no morsel from hir lippes falle,
Ne wette hir fyngres in hir sauce depe.
Wel koude she carie a morsel and wel kepe,
That no drope ne fille upon hire brist;
In curteisie was set ful muchel hir list.
Hire over lippe wyped she so clene,
That in hir coppe ther was no ferthyng sene
Of grece, whan she dronken hadde hir draughte.
Ful semely after hir mete she raught.
And sikerly she was of grete desport,
And ful plesaunt and amyable of port,
And peyned hire to countrefete cheere
Of court, and to been estatlich of manere,
And to ben holden digne of reverence.
But for to speken of hire conscience,
She was so charitable and so pitous,
She wolde wepe if that she saugh a mous
Kaught in a trappe, if it were deed or bledde.

There was a change in English orthography from a fairly phonetic form in the twelfth and thirteenth centuries to less pure spellings in the sixteenth and seventeenth centuries. In the sixteenth century in particular the spelling of a large number of our words seems to have been distorted in the most unjustifiable way by the introduction of all sorts of consonants and double vowels. The writers of the time seem to have been seized with an absurd fancifulness. One might almost imagine that they regarded this distorted spelling as an indication of scholarship. It is in a measure through this want of scholarship on

2. Even Chaucer was not perfectly consistent, the vowel *e* stood for two sounds (nearly = Fr é and è) and *o* stood for two analogously related sounds. Further, he did not represent any of these four sounds uniformly.

the part of writers in those times that we have so much bad spelling to-day. We have not less than seventeen ways of spelling the sound I as in "mind":—

ay	as in	ay	i-e	as in	bite	ai	as in	aisle
i	„	blithe	ui-e	„	guide	ic	„	indict
igh	„	bright	ey	„	geyser	ei	„	either
y	„	scythe	ie	„	belie	is	„	isle
ye	„	bye	eigh	„	sleight	ig	„	alignment
uy	„	buy	eye	„	eye			

thirteen ways of spelling the sound OO as in boot:—

eu	as in	rheumatic	u-e	as in	prune	ou	as in	route
oo	„	boot	ough	„	through	wo	„	two
oeu	„	manoeuvre	ue	„	blue	o	„	prove
ew	„	brew	u	„	jury	oe	„	shoe
ui	„	bruise						

and twelve ways of spelling the sound EE as in see:—

e	as in	he	ay	as in	quay	e-e	as in	precede
ea	„	bead	i	„	machine	ae	„	Caesar
ee	„	beef	ei	„	receive	oe	„	Phoebe
ey	„	key	ie	„	believe	eo	„	people

Not only were the vowel sounds confused by these ignorant and pedantic people, but a number of unnecessary consonants were introduced, most of which disguise rather than indicate the origin and development of the words.

The right thing to do is to throw aside this erroneous spelling and get back to simple phonetics. Several plans have been proposed. Pitman has a system in which every sound has a perfectly distinct sign: there is a great deal to be said for this out-and-out phonetic system, but some people may think the change too drastic to be brought about in a single step. The Simplified Spelling Society has proposed a scheme in which only the letters of the present alphabet are used: the vowel sounds are represented either by single vowels or by digraphs used in the way already commonly accepted. This system has the advantage that the present printers' founts need not be extended and that the ordinary typewriter can be used. The S.S.S. system would be a great improvement upon our present system; and it would be an easy matter to step from it to a shorter method by introducing alternative symbols to represent the digraphs. Our Poet Laureate has compiled a system of symbols that could be used for this purpose.

The Simplified Spelling Society's Scheme.

1. The same sound is always represented by the same letter or letters: eni, jepardi, greev, leep.
2. Consonants have their usual values. C (except in ch), q, and x are not used.
3. Letters not pronounced are not written, and a consonant is not doubled to indicate a short vowel: dout, lam, aktiv, leter, nee.
4. Wherever the z sound (as distinguished from the s) is heard it is written: praiz, windz.

Vowel Sounds.

a	: hat, plat	y	: stylish, tym	au	: haul, aul
e	: men, meni	oi	: oil, boi	œ	: fœ, fœl
i	: bit, bizi	aa	: bazaar, haaf	eu	: eufoni, neu
o	: hot, whot	ai	: wait, grait	oo	: boon, troo
u	: but, bruther	ee	: keen, eet	ou	: found, dround
oo	: book, kood				

It is interesting to follow the history of the spelling of a number of words that are to-day spelt in an irregular manner, and to see how far the irregular spelling is justifiable. This can easily be done, for the history of each word is given in the Oxford Dictionary. In a very large number of cases it will be found that modern spelling is entirely unjustifiable. It is true that the word often sprang from a root that was sounded and spelt in a way widely different from the present form. If we are prepared to change the word back to its original sound and spelling, that might be a reasonable proposition; but to bring into the present word letters that it had when it was differently pronounced is altogether unjustifiable, and in any case we are inconsistent, because we put in some of the letters that the old word had, but not all of them. Moreover, in the course of the history of the word it has usually gone through so many changes that there is no particular reason (from an etymological point of view) for fixing upon the present spelling. It would be very much more logical to fix upon a phonetic spelling, particularly because it has often happened in the history of words that the phonetic spelling was at one time accepted.

The history of a few words, given below, illustrates these points. By looking through the Oxford Dictionary anyone can find hundreds of words that are just as interesting: in fact, if we take at random any word that is spelt to-day in the illogical manner, and look up its history, we shall find that its present spelling cannot be upheld from an etymological point of view.

In the following list of words the figures 11, 12, etc., represent the 11th and 12th century. After the number 20 I have added the spelling proposed by the Simplified Spelling Society.

PHLEGM
Old French
flemme
Mid. Eng.
fleeme
fleume
fleme
Ital.
flemma
Greek
φλεγμα
20 flem.

MYRRH
Arab.
murr
Greek
μυρρα
11 myrra
11–4 murre
14–6 **mir**
15–6 myrr
15–7 myrhhe
17 myrhh
Ital. and Spanish
murra
20 mur

DEBT
13–4 dete
13–6 dette
14–6 dett
det
deytte
15–7 debte
17– debt
"*Artificially spelt* 'debt' *because of Lat.* 'debita' *since* 16*th century.*"
20 det

DOUBT
13–4 dut(e
14 dote
13–6 doute
14–6 dowt(e
douȝte
dought(e
dowght
14–7 **dout**
15– doubt
15–6 doubte, dowbt
"*Artificially spelt* 'doubt' *after Lat.* 'dubitare' *since* 16*th century.*"
20 dout

ACHE
11 acan
12–4 aken, eken
13–9 **ake**
18–9 ache
The verb is historically 'ake' *and the noun* 'ache' (*ch soft*), *cf.* 'bake,' 'batch.'
20 aik

BRUISE
11 brysan
13–5 brisen
13–6 brise
13–7 bruse
14–6 **broose**, brose
bryse
16–7 bruze
17–9 bruise
bruize
20 brooz

ISLE

13–7	ile, **yle**
14	ille, hil (l
14–5	ylle
16	ill
15	ysle, isle
20	yl

AISLE

14–5	ele, hele
15	ille, eille, eyle
15–6	**yle**, ylle
15–8	ile
16–8	isle
18	aile, ayle, aisle

Lat. 'ala' = wing. *Fr. from Lat.* 15 aelle. *In Eng. confused with* (15) yle, ile = island. *Modified after Fr.* aile = wing *as aisle.*

20	yl

GAUGE

15–7	gawge
Scots 16	gadge
18–9	guage
15–	**gage**
	gauge

The present form is a mere blunder. U.S.A. dictionaries have 'gage'

20	gaij

PEOPLE

13–6	peple, pepule
14–5	pepille
14–6	pepill
15	pepylle
17	**peeple**
14–5	poeple
15–	people
	peopel
20	peepel

PRECEDE

Also

15	presede
16–8	**preceed**
	praecede
17	precead
	praeceed
20	preeseed

SCYTHE

11	siðe
13–6	syþe
15	cithe
17	sieth, sight, **syeth**
13–9	**sythe**

Present spelling from

17	scith(e
	scythe
20	syth

BLITHE

11–3	bliðe
13	bliht
14	bligh, bliþ(e
15	blyde
13–7	blith
13–8	**blyth**
14–9	blythe
13–	blithe
20	blyth

BRIGHT

11	beorht, byrht
	bryht
11–3	breht
12–4	briht
13–4	briȝt
14–5	bryȝt, bryght
14–	bright
20	bryt

ANCHOR

A.S.	ancor, ancer, oncer
12–7	anker
16	ancour
	anchor(e
17	**ankor**
	ancker
	anchour

Lat. 'ancora' *occ. erroneously spelt* 'anchora.' *Hence our corruption into* 'anchor.'

20	ankor

Aghast

Old Eng.	gaestan
12–3	ageste
13–6	**agast** (e
16	*occas.* aghast
20	agast

Arraign.

14	arayne
14–5	areyne, ar(r)ene
15	arreyne
15–6	arreygne
	arraynge
16–7	**arrain**(e
	arreign
17	araigne
	arraign(e

After O. French 'araisnier' *and Lat.* 'adrationare' = discourse.

20	arain

Guide

	Also
14–6	**gyde**
	guyde
17	guid

From common Roman 'guida.'

20	gyd

Indict

14–6	**endyte**
14–7	endite
16	endight
17–	indict

From Latin 'indictare.'

20	indyt

Boast

13–7	**bost**
14–6	boste
14–5	bost
16	boist
16–	boast
20	bœst

Alignment

Oxford Dic. says: "*The English form* 'alinement' *is preferable to* 'alignment,' *a bad spelling of the French* 'alignement.' *As* 'line' *is the Eng. spelling of Fr.* 'ligne,' *there is no good reason for retaining the g in the derivative.*"

20	alynment

Choir

α 13	quer(e
13–6	queor
14–6	queer
15–6	qwere, qweer
16	qware
β 15–6	**quyre**
16	quiere, quyer
16–7	quiere
16–	quire
17–	choir

From Lat. from Gk. 'chorus'; 'choir' *is fictitious.*

20	kwyr

Schism

14–7	scisme
15	cisme, cissime
15–6	**sisme**
16	scissym, sciseme
	cysme
16–7	schisme
17	scism, shism
17–	schism

O. Fr. 'cisme,' 'scisme' *Lat.* 'schisma' *from Greek.*

20	sizm

Steak

15	steike, steyke,
	styke
15–6	steke
16	steake
17–8	**stake**
17–	steak
20	staik

	Buy
12–5	buggen, biggen, bigge
14–5	bygge(n, beggn
15	byche
	Also
14–6	bye, **by**
13–7	buye
14	byi, biy
14–5	be
15	byin, beye
16–7	buie
17–	buy
20	by

	Drought (**drouth**)
11	drugath
13	drouhhþe
16–8	drougth
	Also
14	drohut
14–6	droghte
14–	drought
15	**drowte**
20	drout

	Sleight
14–5	slet, sleghte
14–7	sleght(e, slight, **sleyete**
	sleyhte, sleiht
	sleyȝte, sleyght(e
14–	sleight
15	slieght
16	slaight
20	slyt

The advantages of a reformed spelling may be briefly enumerated as follows:—

(1) *Educational Advantages.*

(*a*) With a phonetic spelling children get over the initial difficulty of representing sounds by signs very easily. They can learn to spell correctly in a few months, instead of struggling with spelling for the greater part of the school years. This is proved by a series of experiments in elementary schools, the results of which have been highly successful.

(*b*) Children are encouraged to read, and are not afraid of tackling long and difficult unknown words.

(*c*) So illogical is our present spelling that children in applying unsuccessfully so-called rules of spelling lose faith in the application of rules. This is one of the main defects of our educational system. We teach so many illogical things that a large proportion of the children give up using their reasoning powers. When teaching some subjects we encourage children to ask questions and raise objections. But in spelling lessons the children take the instruction with a submissiveness that dare not ask questions.

(*d*) With phonetic spelling children easily learn to speak well, because the proper sound of the words is invariably indicated by the signs. The hesitation and difficulty in reading aloud and speaking, caused by the old spelling, inflict a deep psychical injury upon children (and see (*f*), below).

(2) *General Advantages.*

(*a*) A reformed spelling would effect a great saving of time and energy, as well as money; all of which could be devoted to more valuable purposes in education.

(*b*) Very few people are able to spell really well. There are no less than 1,100 words about the spelling of which the dictionaries do not agree. Correct spellings have to be learnt by heart, in the manner of Chinese word-forms. Reformed spelling would do away with this.

(*c*) A reformed spelling would make possible the determination of a standard speech. No standard speech can be taught without a system of spelling which truly and constantly represents sound values. (See (*f*), below).

(*d*) Until a standard speech can be fixed upon and taught, the present degradation of our language (of which the Poet Laureate speaks so despairingly) must go on. Clear vowel sounds are rarely heard in unstressed syllables, and even the consonants are often blurred. The beauty of English speech is endangered.

(*e*) The old spelling is the only serious obstacle in the way of English becoming the world language.

(*f*) One of the strongest barriers between classes is the difference in pronunciation. This difference is reinforced by our chaotic spelling. Those who oppose a reformed spelling are guilty of perpetuating class-divisions.

The main arguments that have been brought against the adoption of a reformed spelling are:—

(1) It would cause inconvenience to those of us who have already learnt the present spelling. It should be pointed out in the first place that this inconvenience will be very much less than is commonly supposed: anyone can learn the new system of spelling in the course of a few hours and it is not necessary to read many pages in the new spelling before one reads it with almost as great facility as the old. But suppose we admit that there is some inconvenience to grown-up learners: are there any readers who are so selfish that they would refuse to adopt a system that will save millions of children from the annoyance of illogical spelling and the waste of some years of school education, rather than accept a few hours' or days' inconvenience to themselves? Such an argument is altogether unworthy of right-minded people. We go on opposing the introduction of a reformed spelling

just as we continue to oppose the metric system and a decimal coinage, on account of our inertia and for no logical reason. Now that Japan is adopting the metric system and the Chinese are going in for a phonetic spelling, we are indeed being left behind.

(2) Another argument is, that children who grow up in the new system will be unable to read the present books. This is not true, because it has been found that children who learn the reformed spelling first can learn the old spelling as well, and the total time taken is less than that used in learning the old spelling in the first place. The reason is, that they learn all the phonetically-spelt words in English (which constitute more than one-half the language) on a rational system, and learn the unphonetic words by contrast, the contrasts in some cases being so striking that they are impressed upon the memory. Thus without any more effort than is at present devoted to spelling, children would be able to read in both spellings. But the necessity for doing so would very soon disappear, because the books that are best worth reading would soon be reprinted in the new spelling. What a splendid thing it would be to occupy the publishers for some years to come in reprinting in rational spelling some of the old books that are really worth reading! The republication would act as a kind of sieve, through which good books would pass, worthless books being left behind. We should thus have an automatic purification of our bookshelves. It might be a very good thing for literature as a whole that the majority of the writings of the past should fail to go through the sieve. It would, however, still be possible for students of literature, by the expenditure of a little time and energy, to learn the old spelling sufficiently well to read whatever they may choose.

(3) It has also been argued that confusion would arise between words that are at present spelt differently but pronounced alike (such as rite, right, write). In the first place, it should be pointed out that there are many words spelt alike and sounded differently (such as bow and bow); so that in any case where we lose in one respect we gain in another. But the argument has really very little weight, because we do not find that serious confusion arises in conversation from words that have the same sound but different meanings. The context tells us which meaning is intended, and the same would hold with the new spelling. In any case, if these pious people are so anxious that there should be no possible mistake about the meaning of the written word, why do they not take

steps to alter the 1,500 homonyms, a list of which can be found in Skeat's "Etymological Dictionary"? It is certainly a defect in a language that words of different meanings should be either sounded or spelt alike. If an academy were founded, having charge of the pronunciation and spelling of English words, one of its duties would be to remove such homonyms as caused confusion.

(4) It has also been argued that language is now making continual progress, and that this progress is beneficial. It is further argued that it would be inconvenient to keep on changing the spelling to suit the changing pronunciation. Now as a matter of fact, the change in spelling, in the days before it was standardized in our dictionaries, was very much more rapid than the change in the words. The old manuscripts written in the thirteenth and fourteenth centuries give us a phonetic rendering of many words as we have them to-day: the sound has been unchanged for hundreds of years; and yet through the uncertainty about the right use of vowels and consonants the spelling has been very varied, until Dr. Johnson made a rigid casting of the spelling. Since then it has not altered. With the exception of a comparatively few words, no progress in our spelling has been made for two hundred years. If we want progress in our language we cannot adopt a worse plan than to stereotype our absurd spelling as we have done. With an academy looking after the well-being of our language, natural and useful change would be possible. At present it is practically impossible. There is a slow change in our pronunciation, but it is not accompanied by a change in our spelling.

(5) As a last ditch those who oppose reformed spelling rely upon the following argument: "There are in English two languages, a spoken and a written language. There is no reason why they should be the same: from the very nature of things they cannot be the same. When we read, the written page passes to the brain without pronunciation, and the question of phonetics does not arise at all." This argument gives away our opponents' case absolutely: it admits that already the written language is such a poor representation of the spoken language that the connection between them can no longer be defended. Thus the only logical position for them is, that there need be no connection. This preposterous argument leaves out of account entirely the fact that people sometimes read aloud, that all children have to learn to read, and that we always necessarily make a connection betwen the written and the

spoken language. If the written language was an exact representation of the spoken, we should have only one language to learn instead of two. We must look at this matter from a logical point of view : the object of language is to convey thought, first by sound and second by sign. We can see from the early writers that their intention was to make the written word represent the spoken word on a purely phonetic system. That was a rational method of going to work; and if we only make a slight improvement in the tools they had, we can very easily carry out their intention with success, so as to have the same language spoken and written.

(6) Some plead for the preservation of our ancient beautiful language. I have tried to show that the present spelling, far from preserving the interesting history of the words, only distorts and obliterates that history in a good many cases, and shows a record of nothing more than fancifulness and bad scholarship. An academy should be instituted with power to eradicate these spurious and illogical spellings, and make the language more in accordance with the intentions of pure etymologists. Far from being a bar to progress, such an academy would control the continual advancement of our language.

I have tried to show that in the early days, up to the seventeenth century, the language passed through many interesting chapters. It was then fixed in a chrysalis and remained immovable for two hundred years. I ask now that we shall break the chrysalis and let our winged words form themselves in all their natural beauty. I ask that we shall have a new chapter, which to the future etymologist will be the best and most interesting of them all.

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VII. Manx Mines and Megaliths.

By W. H. Corkill.

(Communicated by W. J. Perry, B.A.)

(Read February 22nd, 1921. Received for publication March 2nd, 1921).

Various forms of megalithic monuments are to be found in the Isle of Man. The majority of them are to be found in the hilly massif which forms the backbone of the Island. The monuments may be classified as follows :—

Stone circles.
Standing stones.
Menhir.
Cairns.
Cists.

A detailed list of the monuments will be found in the Appendix, but, to avoid confusion, our immediate attention will be focussed particularly on the stone circles.

Twenty-two remains, or sites of stone circles, have been found, and, with three exceptions, all are on the hilly massif. Which people built these circles and what were they doing on the Island? From flint weapons and chippings, and fragments of pottery found in or near by the circles, we know these people lived in the period of transition from stone to bronze. That they came to the Island for the purpose of mining for metals will be shown in this paper.

Although many of the stone circles are built with stone obtained locally, there are exceptions to the rule. At Llergydhoo, near Peel, the remains of the stone circle consist of six huge boulders of white quartz of varying size, one or two weighing 10 cwts. each. The nearest place where quartz exists naturally is, I believe, at Cronkbane, two miles away. All the stone circles are near the tops of hills, and this fact might suggest the stones to be glacial boulders, but, after a very close inspection of the stones at Llergydhoo and elsewhere, no evidence of their having been glacial boulders was obtained. At Ballachrink, Maughold, the stones are not of local origin, but appear to be similar to the stones at Gobny-Garwain, at least two miles away. In Orrisdale are two circles, one now entirely buried in the ground, and the ruins of another at Ballaugh, yet this district is composed of glacial moraine which lies at a depth of 173 ft. to 314 ft. upon a sea-worn plateau. Our evidence, therefore, suggests a definite choice of locality for the erection of the circles.

It is remarkable that the circles are in exposed places, being all near the highest point of the hill, some actually on the summit, and every one in a wind-swept, view-commanding position. In the S.W. corner of the Island we have the Mull Circle, with Neolithic hut habitations within half-a-mile. Flint weapons and implements found in these huts suggest that their occupants built the stone circle. On the S.W. of Rushen we have an old mine. Half a mile S.W. of the mine is Cronk Carron, a circle of small stones. Three-quarters of a mile N.N.E. of the mine is the Mull Circle and a series of stone hut circles. At Bradda Head are silver and copper mines. Here again is to be found a stone circle with hut habitations within a mile distant. Ballacorkish Circle is less than half a mile from the lead mine. Kerroogarrow Mine is encircled entirely by megaliths, including one circle. There is no known source of metals in Mann, but is near one or more megaliths.[1] Regions without metals are also without megaliths, with the exception of the northern plain. Such regions may be found in Arbory, German, Patrick, Lezayre, etc., and form quite conspicuous patches upon the map. I therefore suggest that the people who erected the megaliths were miners.

The majority of the mines in Mann are lead mines. Silver, copper and hematite also have been obtained, whilst gold has been reported at several places, usually in small quantities. In support of my theory, I quote the following information received from Mr. P. M. C. Kermode, F.S.A., on the 5th September last. He was conducting excavations for the Manx Antiquarian Society at Clagh Ard, Rushen, and wrote as follows:—

> "In the Cairn which I have opened here, which contained a chamber (and small cist crushed in) with traces of pottery and wood ashes and quantities of white pebbles, I found a piece of Lead Ore (pure Galena) $1\frac{3}{4}$ ins. × $1\frac{1}{4}$ ins. × $\frac{5}{8}$ in. lying within the chamber. It must almost certainly have been mined by the builders or their contemporaries. The Ballacorkish mines are a little distance off."

1. A reference to the list of Megaliths in the Appendix will make this statement clear.


THE ISLE OF MAN.
Stone Circles.
Mines.
Gold (reported).
Pearls.
Flint.
Point of Ayre
BRIDE
Clay Cliffs
Jurby Pt.
Ballaugh
Orrisdale
RAMSEY
Port Lewaigue
MAUGHOLD
MAUGHOLD HEAD
Snaefell
PEEL
Lhergydhoo
Carn Gerjoil
LAXEY
Dhoon Bay
St. Johns
Clay Hd.
Dalby
Niarbyl Bay
South Barrule
Braid
Braddan
DOUGLAS
Douglas Hd.
Port Soderick
Fleshwick Bay
Bradda Head
RUSHEN
Santon
Derby Haven
Castletown
Spanish Hd.
Scale in Miles
0 1 2 3 4 5

Map I.

In view of such evidence, it is difficult to dispute the accuracy of this theory. Many tumuli on the Island still await investigation, and I hope that investigations of the tumuli and cairns between Peel and Orrisdale will disclose some dolmens.

Pearls are reported by Professor Edwin Forbes as having been found in the River Dhoo, near the Braddan Camp, which contains megaliths. Mermaids and mermen figure in our folk-lore. These creatures, I believe, are the maritime equivalent of the fairies, that is to say, wealth-seekers. The fairies were said to have been miners who "lived underground in palaces shining with gold and silver," whilst the mermen and mermaids "lived in palaces under the sea glittering with gems and precious stones." Every source of wealth in Mann appears to have ben exploited by these early folk.

The three circles found on the northern plain would appear to be a stumbling block to the theory, but there are two factors yet to be considered. Firstly, each circle is within a distance of four miles from the metal at Sulby Pass; and, secondly, they are situated in a district abounding with flint. As many flint chippings and implements are found in this district, it would suggest that a flint tool and implement factory are situated here.

I am indebted to Miss Mona Douglas for the following folk-tales bearing upon the theory.

The Laxey Giant.

There's a man living yet has seen the big Faowr (giant) that's taking up Laxey Glen. Himself and his wife are living in the fairy tailor's house in the winter, and up away to the mountains in the summer, and they say they're having great times lifting the ore out of the earth like fluicking (?) stones off a hayfield. Gold, silver and all, they're saying and that's all they're caring to take, so the ones that's working the mines get leave to lift the lead. They were taking all there was *in the old times, hundreds of years ago,* but now they're allowing the miners to have the lead and a bit of silver, etc.

Told to Miss Douglas by John Matt Mylechreest, Glendrink.

Gob-ny-Gowan (Garwain).

There's an old sod castle out on the edge of the sea in Maughold, at a place they are calling Gob-ny-Gowan, because there was an old gowan at one time that had the castle for his house. And he was drawing *gold and silver, copper and lead and white "furring" out of the earth,* etc.


0 ¼ ½ ¾ 1. 2
1 INCH - 1 MILE
The Slack
Fleshwick Bay
Bradda Circle
Mines
Mines
Mines
H.H.
Bradda Hd.
Reservoir
Greyney Mooar 366
Moar
Colby
Ballacorkish
Arbory
Ballabeg
76.
Rowaney
Port Erin Bay
Breakwater
Port Erin
Kentraugh
Black Rocks
Strandhall
Darrag
H.H.
352 Mull Circle
Bay Fine
Mull Hills
Aldrick
Glenchass
Port St Mary
Harbour
New Pier
Poolvaish Bay
Poolvaish
Perwick Bay
Chasms
H.H.
Burroo Ned
Bay Stacka
Sugar Loaf Rock
F.
Spanish Hd.
RUSHEN,
I-O-M.
Mines or Metals
Stone Circles
Cists
Standing Stones &c.
H.H. Hut Habitations
F. Flint.
W.H. Corkill.

Map II.

Told to Miss Douglas by Mrs. Callow, Cardle Veg., Maughold.

It is interesting to note that silver and blende are found at Laxey, and copper, iron and hematite near to Gob-ny-gowan.

Miss Douglas was unable to identify "furring" as a Manx word, but considers it identical with the Irish word "findruine" = tin.

APPENDIX.

(A) MANX MEGALITHS.

This list is not claimed to be exhaustive.

STONE CIRCLES.

Mull Head.
Orrisdale (2).
Llergydhoo.
Braid.
Laxey.
Glen Auldyn.
Kionehenin.
Ballachrink, Maughold.
Ballakelly, Santon.
Bradda Head, overlooking Fleshwick.
Cronk Carron, Spanish Head.
Oatlands.
Colby.
Kerroogarrow, German.
Ballaugh, Old Rectory Glebe.
Ballacorkish.
Arragon Mooar.
Arragon Veg.
Carn Gergoil.
Garwick.
Earykellue, Sulby.

STANDING STONES.

Maughold.
Ballakilpheric, Rushen.
Port St. Mary.
Ballacarnane Mooar.
Ballaglonney.
Grainwick Bay, Santon.
St. Marks.
St. Patrick's Chair.
Braddan Camp.
Kew, German.
Laxey.

CAIRNS AND CISTS.

White House, Michael.
Laxey.
Mooragh, Ramsey.
Rhenwyllin.
Port St. Mary.
Bishopscourt.
Llergy-Rhenny.
Barony, Maughold.
Ballaterson, Maughold.
Barrule.
St. Johns

(B) SACRED WELLS.

Maughold.
Peel.
Mull Hill.
Laxey.
South Barrule.
The Chasms.

(C) Hut Habitations of Stone.

Ballaquane, Dalby.	Burroo Ned.
Mull Hill.	The Sloc.
The Carnanes	

(D) Neolithic Floors or Platforms.

Andreas, The Mooragh.	Rhenwyllin.
„ West Craig.	Cass-ny-hawin, Ronaldsway.
„ The Lagagh.	Port St. Mary.
Bride, Lough Cranstal.	Burroo Ned.
Glen Wyllin.	

(E) Sources of Metal.

Place.	*Metal.*	*Authority.*
Laxey.	G. S. L.	S. L. (cp.) G. (ft.)
Maughold.	G. S. C. L. T. I. H.	C. I. (cp.) G.S.L.T. (ft.) H., W. H. Corkill.
Foxdale.	S. L.	S. L. (cp.)
Bradda Head.	S. C.	(cp.)
Peel.	H.	Mr. Cowley, Chemist, Peel.
Cronkbane.	L.	Mr. J. Cowley, Ballacottier, Andreas.
Sartfell.	L.	do. (cp.)
Ballacottier.	I. (No traces to-day).	do.
Shenvalley, Patrick.	G.	do.
Dalby Mountains.	G.	Mr. W. Cubbon, W.M.A.
Banks Howe.	G.	do.
Douglas Head.	G.	do.
Traie-ny-gill.	L.	do. (cp.)
Knoc-sleemyn.	Metal worked, but now unknown.	do.
Ballacorkish.	L.	(cp.)
Clifton.	G.	Mr. A. Vondy, Ballayockey.
Cornaa.	C.	(cp.)
Abbey Lands, Onchan.	L. Z.	(cp.)
Glen Auldyn.	L.	(cp.)

G. gold, S. silver, C. copper, L. lead, T. tin, I. iron, H. hematite, (cp.) verified by statistics. (ft.) see Folk Tales.

(F) Precious Stones.

Pearls	Braddan (River Dhoo).	Forbes, Fawna Monensis.
Agates, Cornelians	Peel Shore.	Brown's Guide to I.O.M.

(G) MERMAIDS AND MERMEN.

Port Lewaigue.	Lhiondaig Pohllinag.
Garwick.	Joan Mere's House, Chasms.
Fleshwick Bay	Port Erin.

(H) FLINT WEAPONS AND IMPLEMENTS.

Flint weapons and implements have been found in or near by each megalith mentioned in this list. Some of them are of foreign make, being composed of Ophic Calcite, a stone not found in Mann, either *in situ* or as boulders.

Pounders.	Axes.
Crushers.	Knives.
Hammerstones.	Arrowheads.
Whetstones for grinding.	Scrapes, &c.

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MEMOIRS AND PROCEEDINGS
OF
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CONTENTS.

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Manchester Memoirs, Vol. lxv. (1921), *No.* 8

VIII. Variation of Sphæria.

I.—*Sphærium lacustre* (Müller).

By W. E. Alkins, M.Sc

(Read January 25th, 1921. Received for publication May 10th, 1921.)

Introduction. The writer hopes that some studies of variation in the British species of the genus *Sphærium* may be of interest. It is hoped that it will be found possible to obtain each of the four species in sufficient numbers for the purpose of measurement, when at least one series of each will be studied. In the case of *Sph. corneum* (Linné), and *Sph. pallidum,* Gray, no difficulty is anticipated, but in the case of *Sph. rivicola* (Leach) it is doubtful whether the species is at present available in the required quantity in any sufficiently restricted locality in the Manchester district.

The present paper contains the results of an investigation of a rather small series of *Sph. lacustre* (Müller).

Material. The shells were collected by Mr. W. Cartwright and the writer in February, 1920, from a small pond, perhaps thirty feet in diameter, near the Three Lows in North Staffordshire, at an altitude of about 1,050 feet above O.D. This pond is situated on Pendleside shales, a few hundred yards south of the boundary of the carboniferous limestone; while there is no possibility of the pond receiving drainage water from the limestone—for it lies almost on the watershed, the ground sloping away to north and to south—the water must be fairly calcareous, since small pieces of limestone are frequent on the bottom. The floor consists mainly of a slightly clayey mud, which is so finely divided that it only settles very slowly from water. There is practically no vegetation to be seen, except a little grass; microscopic plants are no doubt present. Decaying sycamore leaves are present in great numbers.

The only other mollusca which occur in the pond, to the writer's knowledge, are *Limnœa truncatula* (Müller) and *Pisidia*.[1] The abundance of the *Sphæria* will be appreciated when it is stated that practically three hundred specimens were taken with one scoop in under two hours, all from the outer five or six feet of the pond.

All the living shells taken were collected, cleaned, and dried, care being taken that the valves were tightly closed. There was a number of casualties during the process, and also during that of measurement, and the number of perfect shells was reduced by these to just over two hundred; of these, two hundred were measured, with the results given below.

Measurement. The length, width, and thickness of each shell were determined by means of an optician's sliding gauge provided with a vernier capable of reading to one-tenth of a millimetre. The position of the three axes may be defined as follows:—

Length: From the umbones to the ventral margin, in a direction perpendicular to the latter;

Width: From the anterior to the posterior extremity of the shell, parallel with the ventral margin (i.*e*. perpendicular to the length axis);

Thickness: The greatest thickness of the shell from the (outer) surface of one valve to that of the other, perpendicular to the axes of length and width.

Measurements were made to the nearest one-tenth of one millimetre. Each dimension was noted for each shell, and from the figures thus obtained the values of the ratios $\frac{\text{Width}}{\text{Length}}$ and $\frac{\text{Thickness}}{\text{Length}}$ were calculated. An investigation of the data on elementary statistical lines gave the results which are discussed in the following pages.

Results.

(*a*) *Length, Width, and Thickness Distribution.* The distribution of length, width, and thickness is shewn in Table I below:—

1 *See* Appendix.

TABLE I.

Length, Width, and Thickness Distribution.

	Length		Width		Thickness	
	Length mm.	No. of Specimens	Width mm.	No. of Specimens	Thickness mm.	No. of Specimens
	4·0	3	4·5	1	2·5	4
	4·5	3	5·0	3	3·0	8
	5·0	9	5·5	5	3·5	20
	5·5	20	6·0	8	4·0	57
	6·0	31	6·5	10	4·5	89
	6·5	65	7·0	26	5·0	22
	7·0	58	7·5	38		
	7·5	11	8·0	55		
			8·5	47		
			9·0	7		
Mean, mm. ...	6·39		7·65		4·21	
Standard Deviation, mm.	0·713		0·879		0·535	
Coefficient of Variation... ..	11·16		11·48		12·71	

In all the distribution and correlation work a class interval of 0·5 mm. has been adopted as the most satisfactory. The three distribution curves are all very similar, and suggest at once that the correlation of each pair of variables is high. The resemblance of the curves is borne out by the fact that the coefficients of variation (Pearson) of the three dimensions for the whole series of shells are practically identical for length, 11·16; for width, 11·48; and for thickness, 12·71.

(*b*) *Correlation of Length and Width.* A full correlation table for length and width is given in Table II (the two specimens distinguished in this and the following table are the two to which reference is made later in the sections dealing with the ratio distribution and correlation). It is obvious from a glance at this table that the correlation of the two dimensions is high, and this is confirmed by the high value of the correlation factor (r)— + 0·950.

The equations of regression are :—

(*a*) $L = 0{\cdot}49 + 0{\cdot}771\,W$,

with a standard error of $\pm\,0{\cdot}222$;

(*b*) $W = 0{\cdot}17 + 1{\cdot}171\,L$; standard error, $\pm\,0{\cdot}2735$;

where $\left.\begin{aligned} L &= \text{length,} \\ W &= \text{width,} \end{aligned}\right\}$ in mm.

The regressions throughout have been assumed to be rectilinear.

TABLE II.

Correlation of Length and Width.

	Length, mm.								Total	Mean Length mm.	Standard Deviation	Coefficient of Variation
Width, mm.	4·0	4·5	5·0	5·5	6·0	6·5	7·0	7·5				
4·5	1								1	4·0	—	—
5·0	2	1							3	4·17	·236	5·65
5·5		2	3						5	4·80	·245	5·10
6·0			6	2					8	5·125	·217	4·22
6·5				10					10	5·50	—	—
7·0				8	18				26	5·85	·231	3·94
7·5					12	26			38	6·34	·232	3·67
8·0					*1	38	16		55	6·64	·242	3·65
8·5						*1	41	5	47	7·04	·117	1·66
9·0							1	6	7	7·43	·175	2·36
Total ...	3	3	9	20	31	65	58	11	200	6·39	·713	11·16
Mean Width, mm.	4·83	5·33	5·83	6·65	7·23	7·81	8·37	8·77	7·65			
Standard Deviation, mm.	·236	·236	·236	·320	·279	·259	·238	·249	·879			
Coefficient of Variation	4·88	4·42	4·04	4·81	3·86	3·31	2·84	2·84	11·48			

TABLE III.

Correlation of Length and Thickness.

	Length, mm.								Total	Mean Length mm.	Standard Deviation	Coefficient of Variation
	4·0	4·5	5·0	5·5	6·0	6·5	7·0	7·5				
Thickness, mm. 2·5	3	1							4	4·125	·2165	5·25
3·0		2	6						8	4·875	·2165	4·44
3·5			3	13	4				20	5·525	·2931	5·31
4·0				7	26	24			57	6·15	·3373	5·48
4·5					*1	40	46	2	89	6·775	·2703	3·99
5·0						*1	12	9	22	7·18	·2838	3·95
Total ...	3	3	9	20	31	65	58	11	200	6·39	·713	11·16
Mean Thickness, mm.	2·5	2·83	3·17	3·675	3·95	4·32	4·60	4·91	4·21			
Standard Deviation, mm.	—	·2357	·2357	·2385	·1949	·2546	·2025	·1927	·535			
Coefficient of Variation	—	8·33	7·44	6·49	4·93	5·89	4·40	3·92	12·71			

(*c*) *Correlation of Length and Thickness.* The correlation table for length and thickness is shewn in full in Table III. The correlaton here is not quite so high as in the case of length and width; the coefficient of correlation has the value $+0{\cdot}906$.

The equations of regression are:—

(*a*) $L = 1{\cdot}30 + 1{\cdot}21\,t$,
with a standard error of $\pm 0{\cdot}302$;

(*b*) $t = -0{\cdot}14 + 0{\cdot}68\,L$,
with the standard error $\pm 0{\cdot}226$. (t = thickness in mm.)

(*d*) *Correlation of Width and Thickness.* The correlation table for width and thickness is shewn in Table IV. The coefficient of correlation has the value $+0{\cdot}925$, while the equations of regression are:—

(*a*) $W = 1{\cdot}26 + 1{\cdot}519\,t$,
with a standard error of $\pm 0{\cdot}334$;

(*b*) $t = -0{\cdot}10 + 0{\cdot}563\,W$,
standard error $\pm 0{\cdot}203$.

Thus, the correlation of each pair of dimensions is high.

(*e*) *Distribution of the ratios* $\frac{\text{Width}}{\text{Length}}$ and $\frac{\text{Thickness}}{\text{Length}}$

Data shewing the distribution of the ratios $\frac{\text{Width}}{\text{Length}}$ and $\frac{\text{Thickness}}{\text{Length}}$ respectively are shewn in Tables V and VI. The range covered by each ratio is somewhat surprisingly small: the $\frac{\text{width}}{\text{length}}$ ratio varies from $1{\cdot}13$ to $1{\cdot}29$, only 2 per cent. of the specimens lying outside the limits $1{\cdot}14$ and $1{\cdot}25$; the $\frac{\text{thickness}}{\text{length}}$ ratio varies from $0{\cdot}57$ to $0{\cdot}74$, and in this case $93{\cdot}5$ per cent. of the total number of specimens fall between the limits $0{\cdot}62$ and $0{\cdot}70$. This very restricted variation is reflected in the values of the standard deviations and the coefficients of variation of the two ratios, which are shown at the foot of Tables V and VI.

TABLE IV.

Correlation of Width and Thickness.

	Thickness, mm.						Total	Mean Thickness mm.	Standard Deviation	Coefficient of Variation
	2·5	3·0	3·5	4·0	4·5	5·0				
Width, mm. 4·5	1						1	2·5	—	—
5·0	3						3	2·5	—	—
5·5		4	1				5	3·10	·20	6·45
6·0		4	4				8	3·25	·25	7·69
6·5			9	1			10	3·55	·15	4·23
7·0			6	20			26	3·88	·2107	5·43
7·5				31	7		38	4·09	·1938	4·74
8·0				5	48	2	55	4·47	·1762	3·94
8·5					34	13	47	4·64	·2235	4·82
9·0						7	7	5·0	—	—
Total	4	8	20	57	89	22	200	4·21	·535	12·71
Mean Width, mm.	4·875	5·75	6·50	7·35	8·15	8·61	7·65			
Standard Deviation, mm.	·2165	·25	·4183	·3240	·3036	·2990	·879			
Coefficient of Variation...	4·44	4·35	6·44	4·41	3·73	3·47	11·48			

TABLE V.

$\frac{\text{Width}}{\text{Length}}$ Ratio Distribution.

Ratio : $\frac{W}{L}$	Number of Specimens	Ratio $\frac{W}{L}$	Number of Specimens
1·13	1	1·22	19
1·14	6	1·23	14
1·15	9	1·24	6
1·16	13	1·25	5
1·17	13	1·26	1
1·18	20	1·27	0
1·19	28	1·28	1
1·20	40	1.29	1
1·21	23		

Mean : 1·1964
Standard Deviation : 0·02761
Coefficient of Variation : 2·31

TABLE VI.

$\frac{\text{Thickness}}{\text{Length}}$ Ratio Distribution.

Ratio : $\frac{T}{L}$	Number of Specimens	Ratio $\frac{T}{L}$	Number of Specimens
0·57	1	0·66	42
0·58	0	0·67	34
0·59	2	0·68	22
0·60	2	0·69	15
0·61	1	0·70	7
0·62	9	0·71	2
0·63	17	0·72	3
0·64	19	0·73	0
0·65	22	0·74	2

Mean : 0·6604
Standard Deviation : 0·02575
Coefficient of Variation : 3·90

(*f*) *Correlation of the Ratios* $\frac{\text{Width}}{\text{Length}}$ and $\frac{\text{Thickness}}{\text{Length}}$. It is of considerable interest to enquire whether there is any marked correlation between the two ratios we have been considering, *i.e.* whether there is any tendency for a high $\frac{\text{width}}{\text{length}}$ index to be associated with a high $\frac{\text{thickness}}{\text{length}}$ index, or *vice versâ.* A glance at the correlation table for the ratios (Table VII) shews that there is some tendency for high values of each index to be associated, but that the correlation is far from precise. If we consider the full series of two hundred specimens, the coefficient of correlation of the two ratios has the value + 0·481, while the equations of the regression are:

(*a*) $\frac{W}{L} = 0{\cdot}856 + 0{\cdot}5156\,\frac{T}{L}$,
standard error $\pm\, 0{\cdot}0242$;

(*b*) $\frac{T}{L} = 0{\cdot}124 + 0{\cdot}4485\,\frac{W}{L}$,
standard error $\pm 0{\cdot}0226$.

It appears, however, that the value of the coefficient of correlation as calculated from the data for the full series of shells is unduly influenced by the presence amongst the series of two individuals which have undergone during their growth an injury which has led to their becoming quite noticeably

Mean	Standard Deviation	Coefficient of Variation
1·14	—	—
—	—	—
1·175	·025	2·13
1·135	·005	0·44
1·19	—	—
1·1911	·0281	2·36
1·1753	·0212	1·80
1·1847	·0219	1·84
1·1927	·0218	1·83
1·1967	·0256	2·14
1·2018	·0216	1·80
1·2055	·0204	1·69
1·2080	·0234	1·94
1·2057	·0325	2·69
1·235	·025	2·02
1·2133	·0047	0·39
		—
1·285	·005	0·39
1·1964	0·02761	2·31

TABLE VII.

Correlation of $\frac{\text{Width}}{\text{Length}}$ and $\frac{\text{Thickness}}{\text{Length}}$ Ratios.

Ratio : $\frac{\text{Thickness}}{\text{Length}}$	Ratio : $\frac{\text{Width}}{\text{Length}}$ 1·13	1·14	1·15	1·16	1·17	1·18	1·19	1·20	1·21	1·22	1·23	1·24	1·25	1·26	1·27	1·28	1·29	Total	Mean	Standard Deviation	Coefficient of Variation
0·57		1																1	1·14	—	—
·58																		0	—	—	—
·59			1					1										2	1·175	·025	2·13
·60	1	1																2	1·135	·005	0·44
·61							1											1	1·19	—	—
·62			1		3			3	1				1					9	1·1911	·0281	2·36
·63		1	2	3	4	1	2	3		1								17	1·1753	·0212	1·80
·64		1	1	3	1	2	3	5	2	1								19	1·1847	·0219	1·84
·65			1	3	1	2	3	6	2	3	1							22	1·1927	·0218	1·83
·66		2	1	2	1	7	6	7	9	2	1	2	2					42	1·1967	·0256	2·14
·67			1		1	5	8	7	1	5	4	1	1					34	1·2018	·0216	1·80
·68					1	3	4	4	2	3	3	2						22	1·2055	·0204	1·69
·69				1	1		1	4	3	1	2	1	1					15	1·2080	·0234	1·94
·70			1	1						2	3							7	1·2057	·0325	2·69
·71									1					1				2	1·235	·025	2·02
·72									2	1								3	1·2133	·0047	0·39
·73																		0			—
·74																*1	*1	2	1·285	·005	0·39
Total	1	6	9	13	13	20	28	40	23	19	14	6	5	1		1	1	200	1·1964	0·02761	2·31
Mean	·60	·6267	·6433	·6515	·6438	·6610	·6596	·6565	·6691	·6705	·6793	·6733	·6600	·71		·74	·74	0·6604			
Standard Deviation ...		·0325	·0298	·0211	·0231	·0134	·0180	·0223	·0247	·0216	·0149	·0111	·0228					0·02575			
Coefficient of Variation ...		5·18	4·63	3·23	3·58	2·02	2·73	3·39	3·69	3·23	2·19	1·64	3·45					3·90			

abnormal in shape. In the case of each of these two shells, the position of which has been denoted by an asterisk in Tables II, III, and VII, an injury to the ventral margin at a relatively early stage of growth has caused the length to be considerably less than it would have been if growth had been normal throughout; width and thickness are quite normal, and the consequence is that the two shells are conspicuous for abnormally high values of the ratios $\frac{\text{width}}{\text{length}}$ and $\frac{\text{thickness}}{\text{length}}$ which place them in the extreme lower right-hand corner of Table VII, at a considerable distance from the mass of the specimens. In view of this circumstance it has been thought advisable to recalculate the whole of the constants for the correlation of the ratios, with the omission of these two particular individuals; for the series of one hundred and ninety-eight normal specimens, we have :—

Mean $\frac{\text{Width}}{\text{Length}}$ ratio :— 1·1955.
Standard deviation :— 0·02626.
Coefficient of variation :— 2·20.
Mean $\frac{\text{Thickness}}{\text{Length}}$ ratio :— 0·6596.
Standard deviation :— 0·02460.
Coefficient of variation :— 3·73.

Coefficient of correlation :— +0·419.
Equations of regression :—

(*a*) $\frac{W}{L} = 0·90 + 0·4474 \frac{T}{L}$;
standard error $\pm$ 0·238;

(*b*) $\frac{T}{L} = 0·190 + 0·3926 \frac{W}{L}$;
standard error $\pm$ 0·223.

Hence, the correlation between the two ratios studied appears to cover little more than two-fifths of the whole variation; apart from this variation in the one ratio occurs quite independently of variation in the other.

Summary.

Measurements of length, width, and thickness of a series of two hundred *Sphærium lacustre* (Müller) from a small pond near the Three Lows, N. Staffordshire, has shewn that :—

1. The correlation of each pair of variables (length, width, thickness) is high; the coefficient of correlation exceeds nine-tenths in every case.

2. The variation in the ratios $\frac{\text{width}}{\text{length}}$ and $\frac{\text{thickness}}{\text{length}}$ is remarkably small.

3. The correlation between these ratios is low; the coefficient of correlation is slightly greater than two-fifths; but the presence of two shells, abnormal in shape possibly on account of an injury sustained at an early stage of growth, increased this to practically one-half for the whole series.

4. The data are not sufficiently exhaustive to furnish any reliable information as to the actual development of form of the shell.

The writer wishes to express his cordial thanks to Mr. W. Cartwright for his valuable assistance in collecting and cleaning the shells, and to Mr. J. Harwood, M.Sc., for his help in recording the measurements.

Metallurgical Department, The University,
Manchester.

Appendix.

Note on the *Pisidia* associated with *Sph. lacustre.*

The author has received from Mr. A. W. Stelfox, M.R.I.A., the result of his examination of the *Pisidia* from the station where the *Sph. lacustre* were taken. Mr. Stelfox reports (Jan. 17th, 1921) :—

P. nitidum, Jenyns : One only ! A fine healthy adult, but not a very typical shell.

P. milium, Held : Thirty-five specimens; not quite so rectangular as usual; all adult but three.

IX. Variation of Sphæria.

II.—*Sphærium corneum* (Linné).

By W. E. Alkins, M.Sc., and Maurice Cook, M.Sc.

(Read January 25th, 1921. Received for publication May 10th, 1921.)

Introduction.

In the first paper (**1**) of the present series one of the authors gave an account of the results of the measurement of a series of two hundred *Sphærium lacustre* (Müller) from a small pond near The Three Lows, North Staffordshire. It was then stated that it was hoped that a similar investigation might be carried out in the case of each of the other three British species of the genus *Sphærium* Scopoli. In the present paper are given the results of an inquiry along elementary statistical lines into the variation of the commonest species of the group —*Sph. corneum* (Linné).

Material. The shells used were taken in March 1920 from the Ashton and Guide Bridge Canal, near Dukinfield Station, where they occurred in enormous numbers, associated with *Sph. pallidum,* Gray, *Bythinia tentaculata* (Linné), and *Planorbis albus* (Müller). The bottom of the canal consisted of rather fine ashes; the canal was remarkably free from vegetable matter, while the water was warmed to a slight extent by the hot-water discharge from an adjacent mill. The conditions appeared to be highly favourable to the bivalves, for the number of *Sph. pallidum* was only slightly inferior to that of *Sph. corneum.* On the other hand, the gastropods were by comparison very scarce; they were present on the walls rather than on the bottom of the canal, while the *Sphæria* were, with the exception of a few juvenile examples, on the bottom; a few dozen *B. tentaculata* were seen, but the record of *Pl. albus* is based on a single specimen.

Rather more than five hundred shells of the species under discussion were collected, all shells brought up by the scoop being taken, with the exception of the very smallest. Of these, five hundred were measured; the measurement was carried out exactly as in the case of *Sph. lacustre* (**2**), the three axes length, width, and thickness being noted for each shell; the position of the axes was as defined when dealing with *Sph. lacustre*. Each was determined to the nearest one-tenth of one millimetre, and from the observed data the value of the ratios $\frac{\text{Width}}{\text{Length}}$ and $\frac{\text{Thickness}}{\text{Length}}$ was calculated.

The correlation of each pair of measured axes has been studied, as has that of the two ratios just mentioned.

Results.

(*a*) *Length, Width, and Thickness Distribution.* The distribution of length, width, and thickness is shewn in Table I (in all the distribution and correlation tables a class-interval of 0·5 mm. has been adopted as most convenient). The corresponding curves are all perfectly normal, very slightly asymmetrical, distribution curves, and suggest at once a high correlation of the three dimensions. The similarity of the three frequency polygons is borne out by the close agreement of the coefficients of variation of the three variables—for length, 12·42; for width, 12·92; and for thickness, 14·84.

TABLE I.

Distribution of Length, Width, and Thickness.

Length mm.	Number of Specimens	Width mm.	Number of Specimens	Thickness mm.	Number of Specimens
4·5	5	5·0	1	2·5	2
5·0	12	5·5	4	3·0	13
5·5	36	6·0	9	3·5	43
6·0	94	6·5	16	4·0	108
6·5	156	7·0	40	4·5	179
7·0	85	7·5	82	5·0	90
7·5	58	8·0	104	5·5	45
8·0	32	8·5	95	6·0	18
8·5	17	9·0	62	6·5	2
9·0	5	9·5	40		
		10·0	19		
		10·5	21		
		11·0	6		
		11·5	1		

(*b*) *Correlation of Length and Width.* The correlation table for length and width is given in Table II. The value of the coefficient of correlation, as would be expected from the form of the table, is high— + 0·9598. The equations of regression are:—

$$(a)\ W = 0{\cdot}015 + 1{\cdot}241\ L,$$
with a standard error of $\pm$ 0·301;

$$(b)\ L = 0{\cdot}515 + 0{\cdot}742\ W,$$
with the standard error $\pm$ 0·232.

The regressions are throughout assumed to be linear.

(*c*) *Correlation of Length and Thickness.* Table III sets out the data for a correlation of length and thickness. The correlation is again high, though not so high as in the case of the relationship between length and width; the coefficient of correlation has the value + 0·9254, and the equations of regression are:—

$$(a)\ L = 1{\cdot}505 + 1{\cdot}147\ D,$$
with the standard error $\pm$ 0·314;

$$(b)\ D = -0{\cdot}480 + 0{\cdot}747\ L,$$
with the standard error $\pm$ 0·253.

$$\left[\left.\begin{array}{l} L = \text{Length};\\ W = \text{width};\\ D = \text{thickness};\end{array}\right\}\text{in millimetres.}\right]$$

(*d*) *Correlation of Width and Thickness.* In Table IV are given the data for the correlation of width and thickness. In this case the value of the coefficient of correlation—+ 0·9340—is intermediate between the values which it possesses in the case of the other two pairs of dimensions. The three coefficients are thus in the same order as they were found to be in the case of *Sph. lacustre.* The equations of regression are:—

$$(a)\ W = 1{\cdot}55 + 1{\cdot}498\ D,$$
with the standard error $\pm$0·383;

$$(b)\ D = -0{\cdot}333 + 0{\cdot}583\ W,$$
with the standard error $\pm$0·239.

(*e*) *Distribution of the Ratios* $\frac{\text{Width}}{\text{Length}}$ *and* $\frac{\text{Thickness}}{\text{Length}}$.

Data, shewing the distribution of the ratios $\frac{\text{width}}{\text{length}}$ and $\frac{\text{thickness}}{\text{length}}$ are set out in Tables V and VI. The range over which the ratios vary is very similar to that found for *Sph. lacustre*, though the dispersion is rather greater. The mean $\frac{\text{width}}{\text{length}}$ ratio, too, is somewhat higher than in the case of the latter species—1·242 as compared with 1·196.

TABLE II.

Correlation of Length and Width.

Width, mm.	Length, mm. 4·5	5·0	5·5	6·0	6·5	7·0	7·5	8·0	8·5	9·0	Total	Mean Length mm.	Standard Deviation mm.	Coefficient of Variation
5·0	1										1	4·5	—	—
5·5	3	1									4	4·63	0·2165	4·68
6·0	1	8									9	4·94	·1571	3·18
6·5		3	13								16	5·41	·1952	3·61
7·0			22	18							40	5·73	·2488	4·34
7·5			1	64	17						82	6·10	·1981	3·25
8·0				12	88	4					104	6·46	·1923	2·98
8·5					51	44					95	6·73	·2493	3·70
9·0						35	27				62	7·22	·2479	3·43
9·5						2	29	9			40	7·59	·2472	3·26
10·0							2	16	1		19	7·97	·1969	2·47
10·5								7	13	1	21	8·36	·2736	3·27
11·0									3	3	6	8·75	·25	2·86
11·5										1	1	9·0		
Total ..	5	12	36	94	156	85	58	32	17	5	500	6·668	0·828	12·42
Mean Width, mm.	5·50	6·08	6·83	7·47	8·11	8·71	9·28	9·97	10·56	11·00	8·291			
Standard Deviation, mm.	·3162	·2764	·2635	·2806	·3116	·2339	·2803	·3522	·2353	·3162	1·071			
Coefficient of Variation	5·75	4·54	3·86	3·76	3·84	2·69	3·02	3·53	2·23	2·87	12·92			

TABLE III.

Correlation of Length and Thickness.

Thickness, mm.	Length, mm. 4·5	5·0	5·5	6·0	6·5	7·0	7·5	8·0	8·5	9·0	Total	Mean Length, mm.	Standard Deviation mm.	Coefficient of Variation
2·5	2										2	4·5	—	—
3·0	3	9	1								13	4·92	0·2665	5·41
3·5		3	31	9							43	5·57	·2547	4·57
4·0			4	70	34						108	6·14	·2621	4·27
4·5				15	113	48	3				179	6·61	·3048	4·61
5·0					9	36	42	2	1		90	7·22	·3736	5·17
5·5						1	13	24	7		45	7·91	·3542	4·48
6·0								6	9	3	18	8·42	·3436	4·08
6·5										2	2	9·0	—	—
Total ...	5	12	36	94	156	85	58	32	17	5	500	6·668	0·828	12·42
Mean Thickness, mm.	2·80	3·13	3·54	4·03	4·42	4·72	5·09	5·56	5·74	6·20	4·501			
Standard Deviation, mm.	·2450	·2165	·1816	·2506	·2500	·2602	·2481	·2421	·3028	·2450	0·668			
Coefficient of Variation	8·75	6·93	5·13	6·21	5·66	5·51	4·88	4·35	5·28	3·95	14·84			

TABLE IV.

Correlation of Width and Thickness.

	Thickness, mm.									Total	Mean Thickness mm.	Standard Deviation mm.	Coefficient of Variation
	2·5	3·0	3·5	4·0	4·5	5·0	5·5	6·0	6·5				
Width, mm. 5·0	1									1	2·5	—	—
5·5	1	3								4	2·88	0·2165	7·52
6·0		8	1							9	3·06	·1571	5·13
6·5		2	14							16	3·44	·1654	4·81
7·0			25	15						40	3·69	·2421	6·57
7·5			3	62	17					82	4·09	·2335	5·72
8·0				29	74	1				104	4·37	·2324	5·32
8·5				2	73	20				95	4·59	·2212	4·81
9·0					15	42	5			62	4·92	·2723	5·54
9·5						25	15			40	5·19	·2421	4·67
10·0						2	14	3		19	5·53	·2552	4·62
10·5							10	11		21	5·76	·2497	4·33
11·0							1	4	1	6	6·00	·2887	4·81
11·5									1	1	6·5	—	—
Total ...	2	13	43	108	179	90	45	18	2	500	4·501	0·668	14·84
Mean Width, mm.	5·25	5·96	6·85	7·58	8·24	9·04	9·86	10·53	11·25	8·291			
Standard Deviation, mm.	0·25	·3077	·3150	·3368	·3896	·3960	·501	·3106	·25	1·071			
Coefficient of Variation	4·76	5·16	4·60	4·44	4·73	4·38	5·08	2·95	2·22	12·92			

Mean	Standard Deviation	Coefficient of Variation
1·1850	0·005	0·42
1·20	—	—
1·1850	·005	0·42
1·2200	·02944	2·41
1·2093	·03568	2·95
1·2312	·02494	2·03
1·2230	·02685	2·20
1·2336	·02993	2·43
1·2309	·02923	2·37
1·2409	·02858	2·30
1·2485	·02821	2·26
1·2446	·02622	2·11
1·2616	·02827	2·24
1·2500	·02208	1·77
1·2557	·03090	2·46
1·2618	·01822	1·44
1·2960	·0320	2·47
1·2633	·0330	2·61
1·24212	0·03171	2·55

TABLE VII.

Correlation of $\frac{\text{Width}}{\text{Length}}$ and $\frac{\text{Thickness}}{\text{Length}}$

Ratio : $\frac{\text{Thickness}}{\text{Length}}$	Ratio : $\frac{\text{Width}}{\text{Length}}$ 1·15	1·16	1·17	1·18	1·19	1·20	1·21	1·22	1·23	1·24	1·25	1·26	1·27	1·28	1·29	1·30	1·31	1·32	1·33	1·34	Total	Mean	Standard Deviation	Coefficient of Variation
0·58				2	2																4	1·1850	0·005	0·42
·59						1															1	1·20	—	—
·60				2	2																4	1·1850	·005	0·42
·61				1					1		1										3	1·2200	·02944	2·41
·62	1		2	2		2	1	2	3			1			1						15	1·2093	·03568	2·95
·63				1	1	1		3	4	2	2	2		1							17	1·2312	·02494	2·03
·64			2	1	3	2	5	4	5	4	1	4	2								33	1·2230	·02685	2·20
·65			1	1	3	3	2	7	9	5	2	1	5	3	2						44	1·2336	·02993	2·43
·66			1	1	1	4	7	7	10	3	3	5	3	1						1	47	1·2309	·02923	2·37
·67			1	1	3	3	3	7	6	15	8	9	3	4		4					67	1·2409	·02858	2·30
·68						2	5	5	11	8	4	8	7	4	2	2		2			60	1·2485	·02821	2·26
·69					2	3	3	8	8	13	14	5	2	6	3	3					70	1·2446	·02622	2·11
·70					1		2	3	4	6	5	9	9	2	3	10	1				55	1·2616	·02827	2·24
·71					1			4	3	5	3	8	4	3	1						32	1·2500	·02208	1·77
·72				1			1	2	3	1	1	2	7	3		1		1			23	1·2557	·03090	2·46
·73									1	1	5	4	2	3			1				17	1·2618	·01822	1·44
·74											1		1				2			1	5	1·2960	·0320	2·47
·75										2							1				3	1·2633	·0330	2·61
Total ...	1		7	13	19	21	29	52	68	65	50	58	45	30	12	20	5	3		2	500	1·24212	0·03171	2·55
Mean	0·62		·6429	·6292	·6484	·6557	·6669	·6702	·6688	·6802	·6854	·6836	·6898	·6887	·6800	·6915	·7320	·6933		·70	0·67604			
Standard Deviation ...			·01750	·03772	·03703	·02537	·02214	·02583	·02720	·02502	·02744	·02708	·02671	·02592	·02550	·02716	·01720	·01886		·04	0·23049			
Coefficient of Variation ...			2·72	5·99	5·71	3·87	3·32	3·85	4·07	3·68	4·00	3·96	3·87	3·76	3·75	3·93	2·35	2·72		5·71	4·51			

TABLE V.

Distribution of $\frac{\text{Width}}{\text{Length}}$ Ratio.

Ratio Width/Length	No. of Specimens	Ratio Width/Length	No. of Specimens
1·145	1	1·265	103
1·165	7	1·285	42
1·185	32	1·305	25
1·205	50	1·325	3
1·225	120	1·345	2
1·245	115		

TABLE VI.

Distribution of $\frac{\text{Thickness}}{\text{Length}}$ Ratio.

Ratio Thickness/Length	No. of Specimens	Ratio Thickness/Length	No. of Specimens
0·575	4	·675	127
·595	5	·695	125
·615	18	·715	55
·635	50	·735	22
·655	91	·755	3

In drawing up Tables V and VI a class interval of 0·02 has been adopted; the more extended distribution with the class interval 0·01 is included in Table VII.

(*f*) *Correlation of the Ratios* $\frac{\text{Length}}{\text{Width}}$ *and* $\frac{\text{Thickness}}{\text{Length}}$. An extended correlation table for the two ratios we have been discussing is given in Table VII. While the correlation is very far from precise, there is nevertheless a notable tendency for high values of one index to be associated with high values of the other. The coefficient of correlation has the value +0·448, which is almost exactly the arithmetic mean of the two values returned for *Sph. lacustre* (q.v.). The equations of regression are :—

$$(a)\quad \frac{W}{L} = 0{\cdot}927 + 0{\cdot}466\,\frac{D}{L},$$

with the standard error $\pm$ 0·0283;

$$(b)\quad \frac{D}{L} = 0{\cdot}141 + 0{\cdot}431\,\frac{W}{L},$$

with the standard error $\pm$ 0·0273.

Summary.

Measurements of length, width, and thickness of a series of five hundred *Sphærium corneum* (Linné) from the Ashton and Guide Bridge Canal near Dukinfield Railway Station, Lancs., have shewn that :—

1. The correlation of each pair of variables (length, width, and thickness) is high; the coefficient of correlation varies from + 0·925 in the case of length and thickness to + 0·96 in the case of length and width.

2. The variation in the ratios $\frac{\text{Length}}{\text{Width}}$ and $\frac{\text{Thickness}}{\text{Length}}$ is small, though it exceeds that previously found for *Sph. lacustre* (Müller).

3. The coefficient of correlation for these two ratios has the value + 0·45, which agrees closely with that found in the case of *Sph. lacustre.*

It is not possible from the data available to describe the development of form of the shell.

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REFERENCES.

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2. *Ibid.*, p. 2.

X. Variation of Sphæria.

III.—*Sphærium pallidum*, Gray.

By W. E. Alkins, M.Sc., and J. Harwood, M.Sc.

(Read January 25th, 1921. Received for publication May 10th, 1921).

Introduction. In the two preceding papers (**1**, **2**) of the present series an account has been given of the results of the statistical investigation of a series of two hundred *Sphærium lacustre* (Müller) from a North Staffordshire station and of a series of five hundred *Sph. corneum* (Linné) from the Ashton and Guide Bridge Canal, near Dukinfield station. It is now possible to give similar results for the third of the British species of the genus, and it is hoped that it will be possible to complete the series by an investigation of the one remaining species—*Sph. rivicola* (Leach).

Material. The shells used were taken in November 1920 by Mr. W. Cartwright, B.Sc., and one of the writers (J. H.) from the Ashton and Guide Bridge Canal, near Dukinfield station; this, as may be remembered, is the station which furnished the series of *Sph. corneum* for the previous paper. The conditions under which the shells occur there was described at some length in dealing with that species (**2**, 1), and the fact that the conditions were apparently highly favourable to the bivalves, though perhaps not so favourable to gastropods—which were present only in much smaller numbers—was noticed.

It is interesting to be able to give results for the two species based upon series of shells taken from the same station at a short interval of time, for it is probable at least that the influence of varying environment will thus be eliminated.

Rather more than five hundred shells of the species were collected; all shells brought up by the scoop were taken with the exception of the smallest. Of these five hundred were measured, the method of measuring, position of the measured axes, and method of treatment of the data so obtained, being exactly as described in the case of *Sph. lacustre* (**1**, 2).

Again, the correlation of each pair of measured axes has been studied, as has that of the two ratios $\frac{\text{Width}}{\text{Length}}$ and $\frac{\text{Thickness}}{\text{Length}}$.

Results.

(*a*) *Length, Width, and Thickness Distribution.* The distribution of length, width, and thickness is shewn in Table I (in all the distribution and correlation tables a class-interval of 0·3 mm. has been adopted as most satisfactory). The thickness distribution is very nearly symmetrical, and the asymmetry becomes slightly more marked in the length and width curves. The coefficients of variation for the three dimensions are in very close agreement—length, 9·79; width, 10·81; and thickness, 12·72.

TABLE I.

Distribution of Length, Width, and Thickness.

Length mm.	No. of Shells	Width mm.	No. of Shells	Width mm.	No. of Shells	Thickness mm.	No. of Shells
3·9	1	5·3	1	8·6	64	2·4	6
4·2	2	5·6	2	8·9	63	2·7	8
4·5	6	5·9	2	9·2	56	3·0	27
4·8	10	6·2	6	9·5	30	3·3	94
5·1	22	6·5	5	9·8	25	3·6	113
5·4	63	6·8	6	10·1	11	3·9	112
5·7	71	7·1	13	10·4	7	4·2	93
6·0	117	7·4	24	10·7	2	4·5	34
6·3	102	7·8	41	11·0	2	4·8	9
6·6	60	8·0	64	11·3	—	5·1	4
6 9	28	8·3	73	11·6	3		
7·2	11						
7·5	5						
7·8	1						
8·1	1						

(*b*) *Correlation of Length and Width.* The correlation table for length and width is given in Table II. The coefficient of correlation has the value + 0·9628; the equations of regression are :—

(*a*) $W = -0{\cdot}540 + 1{\cdot}505\ L,$
with the standard error $\pm\ 0{\cdot}2488$;

(*b*) $L = 0{\cdot}773 + 0{\cdot}616\ W,$
with a standard error of $\pm\ 0{\cdot}1592$.

The regressions are in all cases assumed to be linear.

	11·0	11·3	11·6	Total	Mean Width mm.	Standard Deviation mm.	Coefficient of Variation
				1	5·3	—	—
				2	5·6	—	—
				6	6·1	·1414	2·32
				10	6·506	·2245	3·45
				22	7·182	·2886	4·02
				63	7·657	·2195	2·87
				71	8·068	·2263	2·80
				117	8·446	·2500	2·96
				102	8·932	·2410	2·70
				60	9·41	·2528	2·69
				28	9·779	·2651	2·71
				11	10·209	·2314	2·27
	2		1	5	10·94	·3980	3·64
			1	1	11·6	—	–
			1	1	11·6	—	—
	2		3	500	8·5214	·9209	10·81
M	·75		7·8	6·0216			
S D			·2450	·5893			
C			3·14	9·79			

TABLE. II

Correlation of Length and Width.

	Width, mm.																						Total	Mean Width mm.	Standard Deviation mm.	Coefficient of Variation
	5·3	5·6	5·9	6·2	6·5	6·8	7·1	7·4	7·7	8·0	8·3	8·6	8·9	9·2	9·5	9·8	10·1	10·4	10·7	11·0	11·3	11·6				
Length, mm. 3·9	1																						1	5·3	—	—
4·2		2																					2	5·6	—	—
4·5			2	4																			6	6·1	·1414	2·32
4·8				2	4	4																	10	6·506	·2245	3·45
5·1					1	2	12	4	3														22	7·182	·2886	4·02
5·4							1	19	31	12													63	7·657	·2195	2·87
5·7								1	7	41	20	1	1										71	8·068	·2263	2·80
6·0										11	52	41	12	1									117	8·446	·2500	2·96
6·3											1	22	47	29	3								102	8·932	·2410	2·70
6·6													3	24	21	12							60	9·41	·2528	2·69
6·9														2	6	12	8						28	9·779	·2651	2·71
7·2																1	3	6	1				11	10·209	·2314	2·27
7·5																		1	1	2		1	5	10·94	·3980	3·64
7·8																						1	1	11·6	—	—
8·1																						1	1	11·6	—	—
Total ...	1	2	2	6	5	6	13	24	41	64	73	64	63	56	30	25	11	7	2	2		3	500	8·5214	·9209	10·81
Mean Length mm.	3·9	4·2	4·5	4·6	4·86	4·9	5·123	5·363	5·429	5·695	5·922	6·098	6·248	6·445	6·63	6·768	6·982	7·243	7·35	·75		7·8	6·0216			
Standard Deviation, mm.				·1414	·12	·1414	·0799	·1317	·1452	·1798	·1407	·1505	·1562	·1792	·1616	·1714	·1336	·1050	·15			·2450	·5893			
Coefficient of Variation...				3·07	2·47	2·89	1·56	2·46	2·67	3·16	2·38	2·47	2·50	2·78	2·44	2·53	1·91	1·45	2·04			3·14	9·79			

(*c*) *Correlation of Length and Thickness.* In Table III are given the data for the correlation of length and thickness. The coefficient of correlation has the value $+\ 0{\cdot}9288$, which is rather less than that for length and width; the equations of regression are:—

(*a*) $L = 1{\cdot}722 + 1{\cdot}145\,T$,
with the standard error $\pm\ 0{\cdot}2184$;

(*b*) $T = -\ 0{\cdot}779 + 0{\cdot}7532$,
with the standard error $\pm\ 0{\cdot}1771$.

(L = length; W = width; and T = thickness, all in millimetres.)

(*d*) *Correlation of Width and Thickness.* Table IV gives the correlation of width and thickness. The value of the coefficient of correlation is $+\ 0{\cdot}9420$, which is intermediate between those of the other two pairs of dimensions studied. Thus the three coefficients are in the same order in each of the three species that have been examined up to the present. The equations of regression are:—

(*a*) $W = 1{\cdot}705 + 1{\cdot}815\,T$,
with the standard error $\pm\ 0{\cdot}309$;

(*b*) $T = -\ 0{\cdot}411 + 0{\cdot}489\,W$,
with the standard error $\pm\ 0{\cdot}160$.

(*e*) *Distribution of the Ratios* $\dfrac{\text{Width}}{\text{Length}}$ *and* $\dfrac{\text{Thickness}}{\text{Length}}$.

The distribution of the ratios $\dfrac{\text{width}}{\text{length}}$ and $\dfrac{\text{thickness}}{\text{length}}$ is given in Tables V and VI below.

TABLE III.

Correlation of Length and Thickness.

	Thickness, mm.										Total	Mean Thickness mm.	Standard Deviation mm.	Coefficient of Variation
	2·4	2·7	3·0	3·3	3·6	3·9	4·2	4·5	4·8	5·1				
Length, mm. 3·9	1										1	2·4		—
4·2	2										2	2·4	—	—
4·5	3	3									6	2·55	·15	5·88
4·8		5	5								10	2·85	·15	5·26
5·1			15	7							22	3·125	·1394	4·46
5·4			7	52	4						63	3·286	·1245	3·79
5·7				31	39	1					71	3·473	·1565	4·51
6·0				4	63	44	6				117	3·733	·1939	5·19
6·3					7	59	35	1			102	3·988	·1811	4·54
6·6						8	35	16	1		60	4·25	·1988	4·68
6·9							16	11	1		28	4·339	·1697	3·91
7·2							1	6	4		11	4·582	·1850	4·53
7·5									3	2	5	4·92	·1470	3·84
7·8										1	1	5·1	—	—
8·1										1	1	5·1	—	—
Total	6	8	27	94	113	112	93	34	9	4	500	3·756	·4779	12·72
Mean Length, mm.	4·3	4·688	5·122	5·502	5·894	6·198	6·506	6·794	7·2	7·725	6·0216			
Standard Deviation. mm.	·2236	·1452	·1988	·2032	·1952	·1861	·2602	·2400	·2828	·2487	·5893			
Coefficient of Variation...	5·20	3·10	3·88	3·69	3·31	3·00	4·00	3·54	3·93	3·22	9·79			

TABLE IV.

Correlation of Width and Thickness.

Width, mm.	Thickness, mm. 2·4	2·7	3·0	3·3	3·6	3·9	4·2	4·5	4·8	5·1	Total	Mean Thickness mm.	Standard Deviation mm.	Coefficient of Variation
5·3	1										1	2·4	—	—
5·6	2										2	2·4	—	—
5·9	1	1									2	2·55	·15	5·88
6·2	2	4									6	2·62	·1414	5·40
6·5		3	2								5	2·82	·1470	5·21
6·8			5	1							6	3·05	·1118	3·67
7·1			9	4							13	3·092	·1384	4·48
7·4			8	16							24	3·2	·1414	4·42
7·7			3	34	4						41	3·307	·1237	3·74
8·0				36	27	1					64	3·436	·1585	4·61
8·3				3	58	11	1				73	3·641	·1432	3·93
8·6					16	43	5				64	3·848	·1639	4·26
8·9					8	38	17				63	3·943	·1841	4·67
9·2						17	37	2			56	4·12	·1552	3·77
9·5						2	20	8			30	4·26	·1625	3·81
9·8							10	14	1		25	4·392	·1671	3·81
10·1							3	6	2		11	4·473	·2004	4·48
10·4								4	2	1	7	4·671	·2185	4·68
10·7									2		2	4·8	—	—
11·0									2		2	4·8	—	—
11·3											—	—	—	—
11·6										3	3	5·1	—	—
Total	6	8	27	94	113	112	93	34	9	4	500	3·756	·4779	12·72
Mean Width, mm.	5·8	6·275	7·156	7·748	8·292	8·774	9·261	9·818	10·467	11·3	8·5214			
Standard Deviation, mm.	·3317	·1984	·3270	·2880	·2691	·2853	·3535	·3167	·3944	·5196	·9209			
Coefficient of Variation...	5·72	3·16	4·57	3·72	3·25	3·25	3·82	3·23	3·77	4·60	10·81			

TABLE V.

Distribution of $\frac{\text{Width}}{\text{Length}}$ Ratio.

$\frac{W}{L}$	No.	$\frac{W}{L}$	No.	$\frac{W}{L}$	No.
1·31	2	1·39	53	1·46	29
1·32	3	1·40	48	1·47	10
1·33	3	1·41	51	1·48	9
1·34	7	1·42	56	1·49	3
1·35	9	1·43	58	1·50	1
1·36	12	1·44	43	1·51	2
1·37	30	1·45	35	1·52	1
1·38	35				

TABLE VI.

Distribution of $\frac{\text{Thickness}}{\text{Length}}$ Ratio.

$\frac{T}{L}$	No.	$\frac{T}{L}$	No.
0·55	1	0·63	67
·56	4	·64	45
·57	13	·65	33
·58	32	·66	28
·59	40	·67	25
·60	56	·68	8
·61	63	·69	7
·62	77	·70	1

In spite of the fact that the class-interval has been taken as low as 0·01, there is only one slight irregularity (between 1·38 and 1·40 in the $\frac{\text{width}}{\text{length}}$ distribution. This in itself is convincing evidence of the homogeneity of the species—which is indeed borne out by every other character to which any attention has been paid.

(*f*) *Correlation of the Ratios* $\frac{\text{Width}}{\text{Length}}$ *and* $\frac{\text{Thickness}}{\text{Length}}$. An extended correlation table for the two ratios which have been under discussion is given in Table VII. Though the correlation is by no means precise, there is still a definite tendency for high values of one ratio to be associated with high values of the other. The coefficient of correlation has the value + 0·5327, and is thus rather higher than was found to be the case in the other two species. The equations of regression are:—

(*a*) $\frac{W}{L} = 1{\cdot}005 + 0{\cdot}657\ \frac{T}{L}$,
with the standard error $\pm$ 0·0294;

(*b*) $\frac{T}{L} = 0{\cdot}011 + 0{\cdot}432\ \frac{W}{L}$,
with the standard error $\pm$ 0·0239.

Summary.

Measurements of length, width, and thickness of a series of *Sphærium pallidum*, Gray (five hundred) from the Ashton and

l	Mean	Standard Deviation	Coefficient of Variation
	·605	·005	·83
	·5667	·01247	2·20
	·5767	·00471	·82
	·5871	·02250	3·83
	·5856	·01771	3·02
	·5967	·01700	2·85
	·6077	·01856	3·05
	·6023	·02282	3·79
	·6143	·02681	4·37
	·6148	·02799	4·55
	·6186	·02170	3·51
	·6252	·02471	3·95
	·6343	·02268	3·58
	·6284	·02167	3·45
	·6411	·02550	3·98
	·6383	·02574	4·03
	·647	·021	3·25
	·6489	·01729	2·66
	·6533	·02625	4·02
	·67	—	—
	·665	·005	·75
	·64	—	—
	·62158	·0280	4·54
M 32			
S 79			
C 6			

TABLE VII.

Correlation of $\frac{\text{Width}}{\text{Length}}$ and $\frac{\text{Thickness}}{\text{Length}}$ Ratios.

Ratio $\frac{\text{Width}}{\text{Length}}$	Ratio $\frac{\text{Thickness}}{\text{Length}}$																Total	Mean	Standard Deviation	Coefficient of Variation
	·55	·56	·57	·58	·59	·60	·61	·62	·63	·64	·65	·66	·67	·68	·69	·70				
1·31						1	1										2	·605	·005	·83
1·32	1		1	1													3	·5667	·01247	2·20
1·33			1	2													3	·5767	·00471	·82
1·34			2	3	1					1							7	·5871	·02250	3·83
1·35		1	2	2	1	2		1									9	·5856	·01771	3·02
1·36			2	1	2	4		3									12	·5967	·01700	2·85
1·37				4	6	2	8	3	6		1						30	·6077	·01856	3·05
1·38		1	2	9	1	7	2	8	3	1		1					35	·6023	·02282	3·79
1·39		1	1	1	12	7	11	4	3	6	1	4	1		1		53	·6143	·02681	4·37
1·40		1	1	8	1	9	1	12	6	2	3	1	1	2			48	·6148	·02799	4·55
1·41			1		9	2	11	9	8	6	2	1	2				51	·6186	·02170	3·51
1·42					3	13	7	6	11	4	4	3	3	1	1		56	·6252	·02471	3·95
1·43				1	1	3	5	11	13	4	9	5	4	1	1		58	·6343	·02268	3·58
1·44					2	2	11	8	3	6	5	3	3				43	·6284	·02167	3·45
1·45					1	2	2	5	5	5	4	5	3	1	1	1	35	·6411	·02550	3·98
1·46						2	4	5	5	1	4	3	2	1	2		29	·6383	·02574	4·03
1·47								2		5			1	2			10	·647	·021	3·25
1·48									3	2		1	3				9	·6489	·01729	2·66
1·49									1	1					1		3	·6533	·02625	4·02
1·50													1				1	·67	—	—
1·51												1	1				2	·665	·005	·75
1·52										1							1	·64	—	—
Total	1	4	13	32	40	56	63	77	67	45	33	28	25	8	7	1	500	·62158	·0280	4·54
Mean	1·32	1·38	1·3623	1·3744	1·395	1·4009	1·4111	1·4142	1·4212	1·4309	1·4294	1·4321	1·444	1·4375	1·4429	1·45	1·4132			
Standard Deviation ...	—	·01871	·02667	·02549	·02450	·02936	·02950	·02894	·02899	·03431	·02117	·02944	·02993	·02727	·03010	—	·03479			
Coefficient of Variation ...	—	1·36	1·96	1·85	1·76	2·10	2·09	2·05	2·04	2·40	1·48	2·06	2·07	1·90	2·09	—	2·46			

Guide Bridge Canal near Dukinfield railway station have shewn that :—

1. The correlation of each pair of measured axes (length, width, and thickness) is high; the coefficient of correlation varies from $+0{\cdot}9288$ in the case of length and thickness to $+0{\cdot}9628$ in the case of length and width.

2. The variation in the ratios $\frac{\text{Width}}{\text{Length}}$ and $\frac{\text{Thickness}}{\text{Length}}$ is small.

3. The coefficient of correlation of these two ratios has the value $+0{\cdot}5237$, which is somewhat higher than in the case of *Sph. lacustre* (Müller) and *Sph. corneum* (Linné).

4. It is not possible from the data available to describe with any great accuracy the development of form of the shell.

The general features of the variation of all the species of the genus will be discussed when dealing with *Sph. rivicola.*

THE UNIVERSITY, MANCHESTER.
Jan. 20, 1921.

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XI. On the Coral-Gall Prawn *Paratypton.*

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There is no task more fascinating to the naturalist than breaking up a block of some branching coral, such as *Pocillopora* or *Madrepora*, and dislodging from among its boughs the various animals that shelter there; nor of all these latter is there any more interesting than the crab *Hapalocarcinus,* which gives rise to the well-known galls that Semper described in his "Animal Life." This organism has recently been very thoroughly investigated by Potts.[1] He has shown how the female settles in the fork of a young branch while she is still very small and immature; how by her gill-stream she directs the growth of the coral so as to mould it around her into a gall, which eventually closes, leaving only a row of little openings through which the stream flows in and out; how meanwhile she is undergoing the changes by which she reaches the adult condition, with a large, soft-bordered abdomen enclosing as in a pouch below the cephalothorax the limbs which bear the eggs; how midway in this development she is visited by the male, which is free-living and smaller than his mate was even at her first settling; how she feeds on the minute organisms (nannoplankton) brought to her by the stream of water which she draws through the gall; how her mouth-parts are modified in correspondence with this, the slender endopodites of the maxillipeds of the first pair and the exopodites of the second and first having long fringes, presumably for gathering the food much as does the China Crab *Porcellana,* and the inner mouth-parts being greatly reduced in the absence of the need for much mastication; and how, finally, she would appear to lay, after one impregnation,

1. Carnegie Institute, Washington, 1915, 212.

successive broods of eggs, setting free typical crab larvæ of the first zoæa stage, which must pass to the exterior through the outlets of the gall.

Hitherto it has been supposed that all the coral galls were formed by *Hapalocarcinus*. Now, however, Potts has made an interesting discovery which shows that for some a prawn is

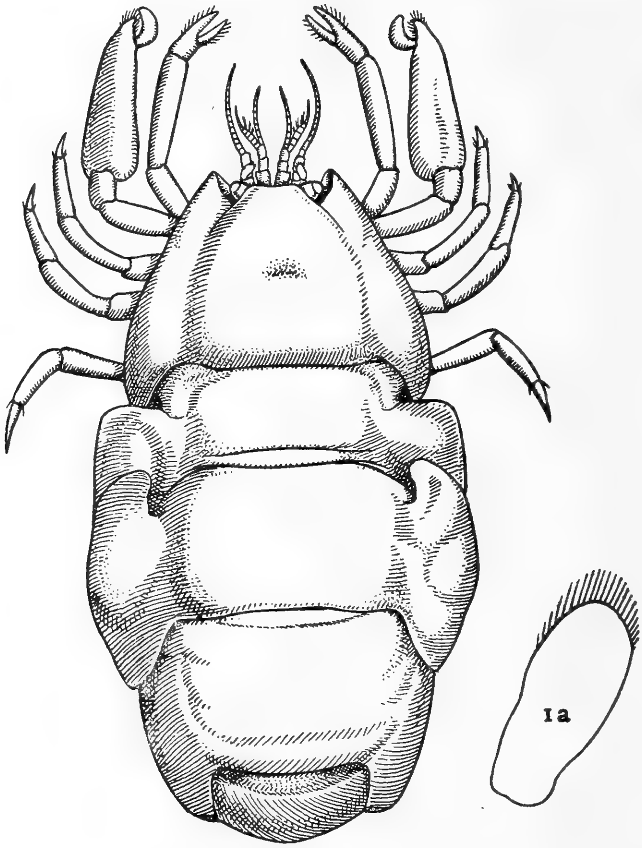


Fig. 1.

Fig. 1. *Paratypton siebenrocki,* Balss, 1914.
Fig. 1*a*, Antennal scale, more highly magnified.

responsible. The prawn was already known, having been described by Balss in 1914,[2] under the name of *Paratypton siebenrocki,* but Balss was not aware of its gall-raising habits. Mr. Potts has kindly placed in my hands his single specimen, which is a female. A male was with her, but was unfortunately

2. *Zool. Anz.*, **45**, 83.

not preserved. They were taken from a large robustly-branched coral of the genus *Acropora* (= *Madrepora*) which was growing at a depth of one or two fathoms in the harbour of Pago Pago, American Samoa. *Hapalocarcinus* has been taken on various corals, but it is not yet recorded from *Acropora*. Details of the structure and mode of formation of the gall are not available, but it was unlike that of *Hapalocarcinus*. though the prawns were well enclosed. It did not project, but was hollowed into the coral.

The body of the female has the heavy, clumsy, and simplified aspect which is commonly presented by members of an active group of animals that have taken to a sedentary life, and are therefore able to further reproduction by sacrificing that elegance which is the result of adaptation to acute perception and swift movement. In this respect, and indeed to some extent in the main outlines of its build, it resembles *Hapalocarcinus,* though, since its anatomy is that of a prawn, the details that make up its habit of body are naturally different from those of the crab, and recall rather the extreme members of the series of similar adaptations which is found in the Pontoniine prawns.[3] Among these, indeed, it shows a considerable likeness to *Conchodytes,* which lives within the shells of bivalve molluscs, though this prawn is less degenerate than *Paratypton*. The back is broad, but its breadth is largely due to spreading branchiostegites and abdominal pleura. Between the branchiostegites the cephalothorax is rather compressed and narrows gently forwards. It is altogether without rostrum, the front being almost straight, and, in Balss' specimen, though not in mine, exposing in a dorsal view the convex middle region of the eye segment. The anterior edge of the branchiostegite projects forward beyond the median region of the carapace and bears no spines or angles whatever. The abdominal pleura, particularly the first four, are very large and, arching, enclose on the under side of the body a great brood-pouch in which lie the abdominal limbs. The last pair of limbs, with the telson, complete the pouch wall. The abdominal segments are altogether without spines or angles save that the hinder angles of the sixth segment project sharply. The cuticle of the body is everywhere very thin and perfectly smooth.

3. A group of prawns treated by some authors as a sub-family of the Palæmonidæ, and by others as a separate but closely related family. Many of its members are commensal, or at least associated, with sessile or sub-sessile organisms.

In life the animal is colourless and almost transparent. As might be expected, the *sensory appendages* are not well developed. The eyestalks are short and broad, and the eyes small and pale. The antennule is of the normal Palæmonid type, but short and stout, with sub-equal flagella, no longer than the stalk, of which the outer, though thickened as usual in its basal half, is not cleft. The stylocerite is blunt, but the outer distal angle of the first joint is sharply produced. The statocyst appears well developed. The antenna has a stalk not quite as long as that of the antennule with a flagellum about twice as long as the antennular flagella,[4] and a small, sub-oval, fringed scale, which barely reaches the end of the stalk.

In considering the *mouth-parts* of the animal, one is drawn inevitably into speculation as to its food and mode of feeding. *Hapalocarcinus,* as has been said, feeds on the nannoplankton, and it is natural to suppose that *Paratypton* does the same, in which case we should expect to find its mouth-parts modified in the same way as those of the gall crab. It will be convenient to study these parts in order from behind forwards.

The third maxilliped has neither exopodite nor epipodite. For the rest, it is very suggestive of those of certain Pontoniinæ. In it as in them, by fusion of propodite and dactylopodite, and again of basipodite, ischiopodite, and meropodite, the limb becomes four-jointed. The second joint is long and broad; the distal two considerably narrower. All these joints are fringed with bristles, but those are not exceptionally long or numerous. The long joint has a concave inner edge, and is not flat but somewhat warped. The result of this disposition is that even the broadest of the third maxillipeds of such prawns do not close the mouth-area below as do those of the crabs, but wall it in at the sides, leaving underneath it an opening, partly fenced by bristles. The second maxilliped is also without epipodite or exopodite. In other respects it is that of the Palæmonidæ and relative families. The organ, formed by the last two joints, for gathering in the food and passing it to the deeper-lying jaws is rather shorter than usual, and the limb a good deal resembles that of *Phyllognathia* (Gnathophyllidæ). The first maxilliped is quite of the type which is normal in the same group of families. Its epipodite is distinctly lobed and its exopodite truncated and somewhat more hairy than usual.

4. Balss says it is scarcely longer. Possibly he was describing a specimen in which it was broken.

The maxilla is unlike that of the Palæmonidæ in lacking both the cleft lobes. In this respect it recalls the Anchistioididæ and the Crangonoida. The maxillule has both laciniæ a good deal drawn out. According to Balss, they are united for some distance at the base. Unfortunately, one of the pair removed from my specimen was accidentally destroyed, and in the other the inner lacinia is missing. The very strong spines which are usually borne at the end of the outer lacinia are in *Paratypton* reduced to short, conical vestiges, which in the middle of the row almost disappear. In the endopodite, the end lobe is reduced to a low, rounded prominence, and the lobe proximal to it, which is usually curved to hook round the edge of the metastoma, is long and conical, and ends in a very strong spine, like that which in Palæmonidæ usually tips the endopodite of the first maxilliped. The lower lip (metastoma) is much like that of the Palæmonidæ, but its cleft is partly closed and converted into a gutter, which runs between two fleshy pilasters, and leads to a notch of the edge of the organ, at the sides of which the pilasters end in knobs. The mandibles are placed in a mouth-chamber like that which I have described for the Palæmonidæ, bounded behind by the metastoma, in front by the labrum, and at the sides by the bases of the mandibles. They have no palp. Their form is on the whole that of the Palæmonidæ, but they show two remarkable features. The molar process is reduced to a conical spike, the end of which, however, is truncated and bears on its edge one large tooth and a row of smaller ones. This apparatus differs a little on the two mandibles. The slenderness of the molar process is a little reminiscent of the Gnathophyllidæ. The incisor process ends in what seems at first a plain edge like that of *Hapalocarcinus*, but is in reality very finely toothed, the notches between the minute, sharp teeth running for a short distance over the surface of the process as parallel furrows separated by ridges continuous with the teeth. At one end of edge is a stouter tooth. The whole has the appearance, not of having arisen by a multiplication of the coarse teeth which are usual on the end of the incisor process, but of being an organ *sui generis*. The labrum is of the usual Palæmonid form.

It will be seen that the mouth-parts of *Paratypton* present no very abnormal feature. Their general aspect is that of the same organs of the Palæmonidæ, and in particular the third maxilliped recalls the Pontoniinæ; but certain features are reminiscent of the Gnathophyllidæ and Anchistioididæ. There is nothing which strongly suggests a diet of plankton. Certainly there is no conspicuous apparatus for gathering it, though possibly both here and in some Pontoniinæ the broad third maxilliped may be of use by forming a wall to the mouth region and thus enabling finely divided food to be kept under control. The peculiarities of the maxillules are probably connected with those of the metastoma, but what their effect may be it is impossible to say. The most striking features are those of the mandible, and here there is probably a definite adaptation to some specific food. But there is nothing to show that that is plankton. For information on this point we must wait till further knowledge of the habits of the prawns, and of the structure of their galls, shall have been gained. There are several possibilities. The openings of the galls are probably small, but we are quite in the dark on this point, and it may be that the prawn receives relatively large morsels of food through the agency of its stream. Or, it may be that the animal feeds, as *Hapalocarcinus* was formerly supposed to feed, on the fleshy parts of the coral, which in that case must regenerate rapidly. Or, again, it may be that *Paratypton* has some means, not obvious when it is not feeding, of gathering the nannoplankton. Possibly it may live, as certainly does the crab *Melia* which carries anemones in its chelæ, by stealing food caught by the polyps. If this be accompanied by mucus, the surprisingly normal character of the mouth-parts of the prawn could be accounted for in the same way as that of the same organs in *Pinotheres*, commensal with bivalve molluscs, and probably also of those Pontoniinæ which have a like habitat. In these organisms the food is not in fact finely divided, but consists of the strings of mucus with entangled food which the host is forming for its own nourishment.

The *legs* are rather short and stout, with rounded joints, which have no spines or sharp angles, and for the greater part of their length bear sparsely a few short hairs, though at the ends of the propodites these structures are longer and more numerous. This reduction of the hairs of the legs, many of which are undoubtedly tactile, is a part of the degeneration of the sensory apparatus in sedentary Crustacea; and, taken in connection with the clumsiness of the movements of such animals when they are removed from their hiding-places, lends support to Doflein's suggestion that it is a function of the tactile hairs of Crustacea to enable their possessor to coordinate the movements of its limbs. They would naturally be retained at the end of the leg, since that is still in constant contact with external objects. The first pair of legs is of the form which that limb has in the Palæmonidæ generally, and its hairy chela is no doubt used in the ordinary way for cleaning the body and limbs. The second pair are equal and alike. Their chelæ are somewhat reminiscent of the large chela of an Alphæid. They have a very large, oblong "hand," compressed in the near half, but a little widened and oddly depressed at the base of the fingers, which are short. The moveable finger is a very clumsy, blunt hook, biting along and across a still smaller fixed finger, which is shaped like the prow of a boat, with sharp edges and point, and bears a number of soft hairs on its sides. What use the animal can make of these rather remarkable organs it would be unprofitable to attempt to guess. The walking legs end in small, simple, sharp-pointed, curved dactylopodites. As usual, they differ somewhat in their proportions, the hinder pair being the most slender.

The *gill-formula* is that of *Conchodytes*—a row of five pleurobranchs above the legs of each side—though a few minute folds in the position of the pleurobranch of the third maxilliped probably represent that gill. Thus here, as in the Pontoniinæ, a reduction of the gill apparatus accompanies a sedentary life. The *abdominal limbs* of the first five pairs are large, and are borne each at the end of a ridge which runs outwards across the underside of the pleuron. The basipodite is long and flat, and in the fifth pair, which is shorter than those before it, is widened, and probably strengthens the hinder part of the brood-pouch. In the first pair the endopodite is very small; in the others endopodite and exopodite are sub-equal, pointed, fringed plates. An *appendix interna,* with the hooked spines well developed, is borne on the endopodite in the second to fifth pairs, as in Palæmonidæ and Gnathophyllidæ. It seems probable that these broad and well-formed limbs serve, not only to carry the eggs, but also to maintain, or from time to time to reinforce, the current in the gall; as in a resting *Leander* they are used to renew the water below the body. The uropods are well-developed and resemble those of the Pontoniinæ.

I am unfortunately compelled by an accident, which cost me the loss of the telson of my specimen as well as of one of its maxillules, to describe this organ from memory, aided by some rough notes and an even rougher sketch. It is broad and sub-triangular with convex sides and rounded end. The most conspicuous structures on its edge are some half-dozen strong, unfeathered bristles on each side, around the end. At the end stand also on each side two short, conical spines, the outer pair rather larger than the inner. At some distance forward on each side, a similar spine, of about the same size as the inner pair at the end, stands in a notch. There are no spines on the dorsal surface. The whole structure is very unlike the telsons of the Pontoniinæ, but rather suggestive of those of the Anchistioididæ. The *length* of the specimen is about 20 mm.

The foregoing description relates solely to the female. It is highly desirable that we should know how the male differs from her. Mr. Potts informs me that he is not much smaller. Since Balss, who had males, did not describe this sex, we may infer that the differences between the two are not greater than those which exist, for instance, between the sexes in *Conchodytes*. It would seem that, as in various other sedentary Crustacea, they associate in pairs, but it would be interesting to have further particulars of the partnership. At what stage is the female when the male joins her, and how long does he live with her? What influence has he upon the formation of the gall, and is he alive when it closes? Does impregnation take place more than once? These and other such questions remain to be answered. In any case, it is pretty clear that the female is immured for life. Mr. Potts informs me that the female he sent me lived for two or three days in sea-water and was quite healthy when he killed it. In freedom it was very slow-moving and clumsy.

Balss' specimens came from Kosseir on the Red Sea, and from Jaluit. They appear to belong to the same species as mine, the only differences that I can discover being that in the length of the antennal flagella, mentioned in a footnote above, and the exposure of the eye segment in dorsal view. In view of the facts of the distribution of Decapod crustaceans in the Indo-Pacific, it is probable that the animal exists throughout that area. It seems to be much rarer than *Hapalocarcinus*, but this is very likely due to some difference in habitat which causes it to be less often found. It was certainly not contained in any of a number of galls that I opened in the island of Minikoi, in the Indian Ocean.

It will be seen that there are many unsolved problems relating to the bionomics of *Paratypton*. To these may be added that of its affinities. Not unnaturally, in view of its habits and many of its features, Balss placed it among the

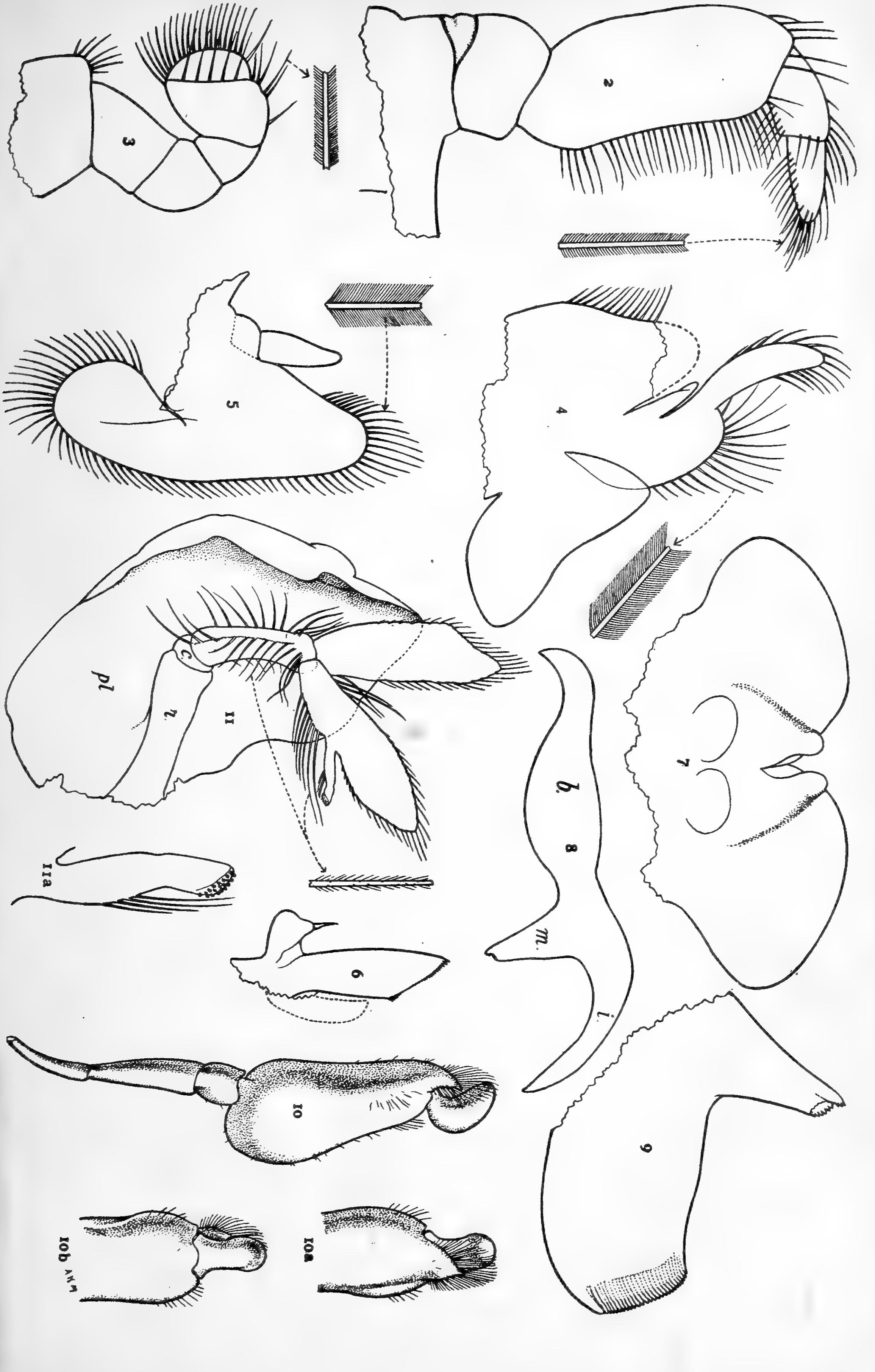
Pontoniinæ. I am, however, inclined to dissent from this conclusion. It is unlike the Pontoniinæ prawns in several features. Foremost of these is its telson, which has quite a different facies. To that may be added certain features of the mouth-parts which, as I have shown, are in some respects unlike those of the Pontoniinæ and suggest affinities with some of the families which connect the Palæmonidæ with the Crangonidæ. The uncleft outer flagellum of the antennule is also a point of difference from the Palæmonidæ, but this might quite well be due to retrogression connected with a sheltered life, and is approached in some Pontoniinæ. The inflated carapace a little suggests that of the Hippolytid *Pterocaris*, but this likeness is belied by the whole of the rest of the anatomy.

Taking the evidence as a whole, I am inclined to place *Paratypton* near the point to which the Palæmonidæ, Anchistioididæ, and Gnathophyllidæ converge, but I think that it would at present be rash to attempt to define its position more precisely than this.

The problem is complicated by the fact that the structure of the prawn is obviously greatly modified by its unusual mode of life. This is of course conspicuously true of its habit of body. Others of its features, such as those of the mouth-parts and chelæ, do not differ from those of free-living forms more than the latter differ among themselves, and it is at present impossible to say how far, if at all, their peculiarities are connected with the habit of living in a coral-gall.

Figs. 2—11*a*.

Fig. 2. *P. siebenrocki,* third maxilliped.
Fig. 3. " , second maxilliped.
Fig. 4. " , first maxilliped.
Fig. 5. " , maxilla.
Fig. 6. " , maxillule.
Fig. 7. " , metastoma.
Fig. 8. " , mandible.
b, base; *i,* incisor process; *m,* molar process.
Fig. 9. *P. siebenrocki,* end of mandible, more highly magnified.
Fig. 10. " , great cheliped.
Fig. 10*a*. " , end of chela, from below.
Fig. 10*b*. " , " " " above.
Fig. 11. *P. siebenrocki,* second abdominal pleuron, with limb.
c, coxopodite; *pl.* pleuron; *r,* ridge, to which limb is attached.
Fig. 11*a*. Appendix interna, more highly magnified.



Figs. 2—11*a.*

XII.—Theory of the Solvent Action of Aqueous Solutions of Neutral Salts on Cellulose.

By HERBERT E. WILLIAMS.

(Read April 12th, 1921. Received for publication September 20th, 1921.)

The object of this paper is to demonstrate that the solution of cellulose in certain aqueous solutions of neutral salts is largely a physical phenomenon, chemical reaction playing but a small part; that it is independent of the chemical nature of the salt, but that it depends directly on certain physical properties of the concentrated salt solution, and on the power of the salt to form hydrates in solution.

During a research on the preparation and properties of the metallic thiocyanates and their double salts, it was noticed that the concentrated solutions of several of these salts had a profound action on paper. Several years later attention was again directed to this subject, and a systematic study of the action of the concentrated solutions of the thiocyanates on cellulose was undertaken. A number of pure thiocyanates were prepared, and the action of their concentrated solutions on cellulose carefully observed, both in the cold and on heating. As the action on cellulose varied a little with the particular form of cellulose used, and the treatment it had undergone, the experiments described in this paper were carried out with chemical wood pulp taken from the same bulk sample; thus insuring a cellulose of a uniform condition.

The solvent action of the solution was determined by suspending a small portion of the chemical wood pulp in the solution and allowing the mixture to evaporate by slow boiling. A sample was taken out from time to time and examined on a glass slide under the microscope, and the temperature of the boiling point of the solution noted when fibre structure was no longer visible and the drop on the slide appeared perfectly uniform and homogeneous. The solution was then diluted and the precipitated cellulose washed and examined for possible evidence of structure. The experiment was then repeated, taking in this case a solution but a few degrees below the boiling point noted in the first experiment. When the salt solution is obtained of the right concentration for dissolving the cellulose, solution of the cellulose may be obtained in most cases below the boiling point of the salt solution, but in all cases, in order to obtain complete solution by this method it is necessary to heat the mixture to a minimum temperature varying between 90—133° C., depending on the particular salt solution used. With pure neutral calcium thiocyanate solution boiling at 133° C., solution of the chemical wood pulp may be obtained by heating to 90° C.

This work resulted in the discovery that concentrated solutions of the calcium, strontium, magnesium, manganese, and lithium thiocyanate were each solvents for cellulose when heated.

On careful examination of the solutions of those salts which dissolved cellulose it was noticed that in each case the solution of sufficient concentration to dissolve cellulose was abnormally viscous, a property shared by zinc chloride solution, which has long been known to be a cellulose solvent.

This idea of a possible relationship between the viscosity of a salt solution and its solvent action on cellulose was submitted to critical examination, and the viscosities of the solutions of a number of thiocyanates were determined at different concentrations, at constant temperature, by means of the Ostwald viscometer.

These results showed that as the concentration increased the viscosities of the solutions of the calcium, strontium, magnesium, manganese, lithium, and aluminium thiocyanates rapidly increased, whereas the solutions of the potassium, sodium, ammonium, nickel, and zinc thiocyanates increased but slowly; the former group being much more viscous than the latter for equal molecular concentrations.

Now the concentrated solutions of the calcium, strontium, magnesium, manganese, and lithium thiocyanates had been found in the course of this work to be solvents for cellulose, but no solution of the cellulose was obtained with the aluminium thiocyanate solution, although the viscosity of its concentrated solution was high. With the thiocyanate solutions of low viscosity such as those of potassium, sodium, etc., no solution of the cellulose was obtained at any concentration. With the one exception then of the aluminium salt, the high viscosity very sharply differentiates those aqueous solutions which dissolve cellulose from the non-solvent solutions of low viscosity, and clearly indicates some relationship between a high viscosity of the salt solution and the property of dissolving cellulose.

A further examination of these cellulose solvents revealed the fact that not one of them dissolved the cellulose until the boiling point of the concentrated solution rose to 133—134° C. or over. This fact is strikingly shown by the solutions of the strontium and manganese thiocyanate which are more viscous than the calcium salt at the concentration at which the latter dissolves cellulose, yet neither of these salt solutions becomes a cellulose solvent until concentrated to the boiling point of 133° C. This point would seem to explain the non-solvent action of the aluminium thiocyanate solution, the most concentrated solution of which did not boil above 121° C. under atmospheric pressure.

At this stage a very large number of the solutions of the thiocyanates and double thiocyanates were examined, and the viscosity of the solutions at various concentrations determined. Calcium chloride, a very soluble salt and one with a viscous solution, was also examined in this manner. The figures thus obtained were then plotted against the corresponding boiling points of the solutions.

As no solution of these salts was so far known which dissolved cellulose under a concentration corresponding with a boiling point of 133° C., this figure was taken as the minimum boiling point of a solution for a cellulose solvent; and also as not one of these solutions, even those boiling above 133° C., was a cellulose solvent unless the solution had a viscosity at 100° C. of at least 3.3 times that of water at 20° C., these two points were taken as the lower limits of these properties in the solvent action of these solutions on cellulose. On these facts it was temporarily assumed that before an aqueous salt solution could dissolve cellulose, it must have a boiling point of 133° C. or over, and a viscosity at 100° C. of 3.3 times that of water at 20° C.

In *Fig.* 1 the reason for fixing these two lower limits is very clearly shown, particularly by the lithium, strontium, barium-manganese $BaMn\,[CNS]_4$, and cerous thiocyanate, for the last three of these have a much greater viscosity than calcium thiocyanate of cellulose solvent strength, yet they do not become solvents unless concentrated until the boiling point of the solutions rises to 133° C. On the other hand lithium thiocyanate solution does not attain the necessary viscosity until the boiling point rises to 165° C., at which concentration it becomes a cellulose solvent.

With the exception of the solutions of calcium chloride, and potassium-manganese thiocyanate $K_2Mn[CNS]_4$, all these solutions were found to be cellulose solvents at the particular boiling point concentration and viscosity at which the curve crosses into the area marked "cellulose solvent area."

The two exceptions mentioned above were at first difficult to explain, and it was realised that there was at least another factor to be brought to light before the necessary physical constants for a cellulose solvent could be established.

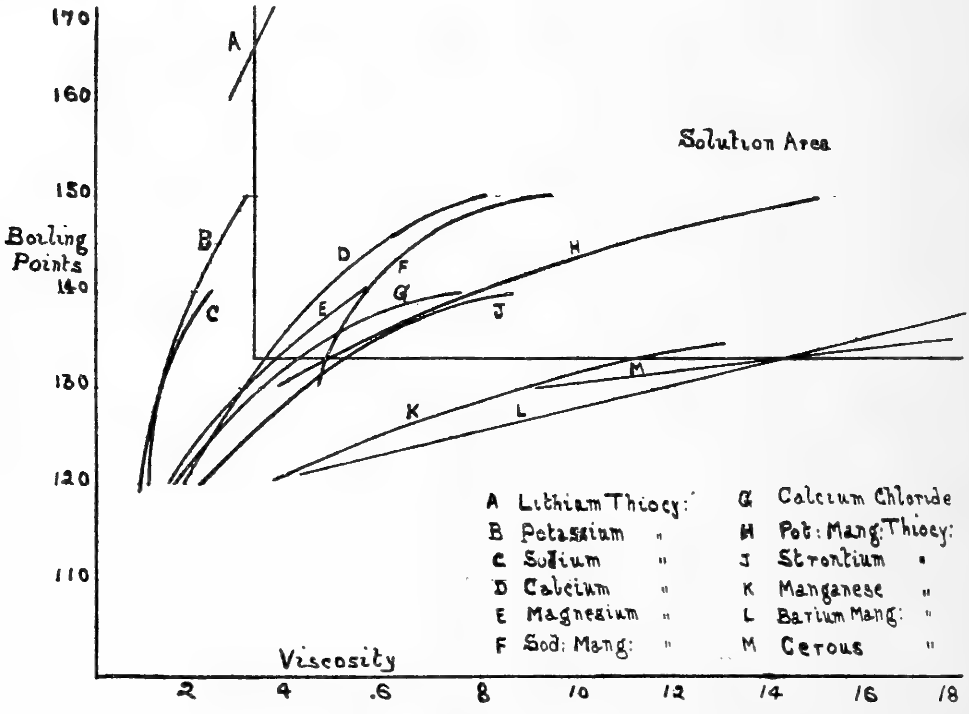


Fig. 1.

A consideration of this question suggested the following line of reasoning. If one of the necessary preliminary conditions before the cellulose dissolves is the hydration of the cellulose, it is evident that if the water present in the aqueous solution is attached to the salt with too great an affinity, it will not hydrate the cellulose, but on the contrary will tend to dehydrate it; and no solution of the cellulose can result, although the concentration and viscosity conditions are fulfilled.

In order to test this point the heat of dilution of these aqueous salt solutions was determined at different concentrations, and the molecular heat of dilution plotted against the boiling points. These determinations were not of high accuracy owing to the difficulties of such operations in a works laboratory; but the results obtained were sufficient to give the necessary explanation. It may be of interest here to remark that early in this work it was found that to dilute the solutions of the different salts with the same quantity of water, as in the usual practice, gave results that were without definite meaning. On gradually diluting many of these concentrated solutions an evolution of heat is at first observed up to a point; further dilution beyond that point results in an absorption of heat. With concentrated calcium thiocyanate solution heat is evolved on gradual dilution until the molecular ratio of salt and water is 1 :20; further dilution beyond this point results in an absorption of heat. With strontium thiocyanate solution this point is reached at the ratio of 1 :18; and calcium chloride solution at about 1 :30. In order to obtain the true molecular heat of dilution it is necessary first to determine this ratio for the particular salt under observation, and to determine the heat evolved by diluting the concentrated solution to this point.

The results obtained in this manner showed that the concentrated calcium chloride solution has a very high heat of dilution, much higher than that of any of the other salts examined; whereas the potassium-manganese thiocyanate solution has a large negative heat of dilution. The former solution therefore at this concentration would have too strong a dehydrating action to dissolve cellulose, but the latter would have neither a dehydrating nor a hydrating action.

As calcium chloride with so large a heat of dilution was a non-solvent for cellulose, it was thought possible that if the calcium thiocyanate solution could be made concentrated enough, a point should be reached when its heat of dilution would be so great that it would cease to be a cellulose solvent. Experimental evidence showed this to be true for a solution concentrated to a boiling point of 150° C. and over. At this concentration no cellulose was dissolved even after heating for some time, though the fibres appeared highly swollen. The addition of a very small amount of water, sufficient to drop the boiling point of the solution to 148° C., caused the cellulose to dissolve rapidly.

In a similar manner strontium thiocyanate solution of boiling point 140° C. and upwards proved to be a non-solvent for cellulose, and magnesium thiocyanate solution of boiling point 150° C. and above. Slight dilution to reduce the boiling point below these figures caused almost instantaneous solution of the cellulose.

From these facts it appears evident that we could plot out the molecular heats of dilution against the viscosities of the solutions for various concentrations, and mark off a sharply defined area; so that any aqueous solution of a salt of boiling point 133° C. or over, the molecular heat of dilution and

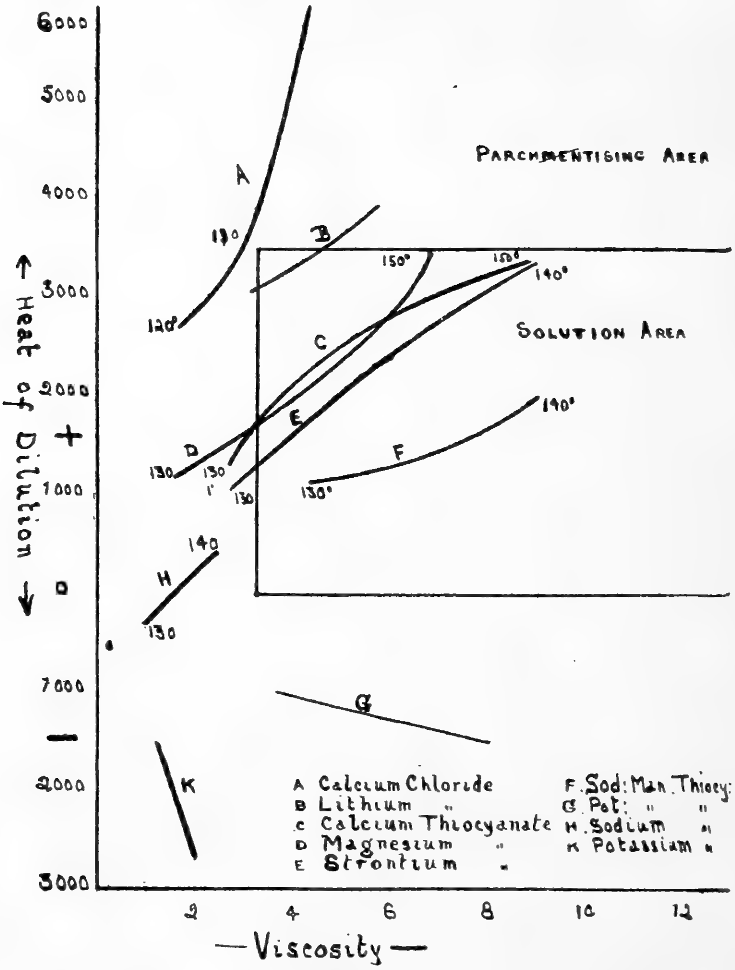


Fig. 2.

viscosity of which fell within the prescribed area, would be a solvent for cellulose, and not otherwise. And further it would begin to dissolve cellulose, at all concentrations corresponding with boiling points above 133° C on the viscosity and heat of dilution curve within this area, and cease to be a solvent where the curve passed out and beyond that area.

This area could of course be very clearly defined on a three dimensional scale model, marking the viscosity, heat of dilution, and boiling points of the solutions on the three axes.

It will be noticed on examining the curves given in *Fig.* 2 that whereas potassium-manganese thiocyanate is well out of the solvent area owing to its negative heat of dilution, the corresponding sodium double salt enters the area. Experimentally all efforts to dissolve cellulose in the potassium-manganese thiocyanate solution of any concentration have failed, but it readily dissolves in the solution of the sodium salt boiling at 134° C.

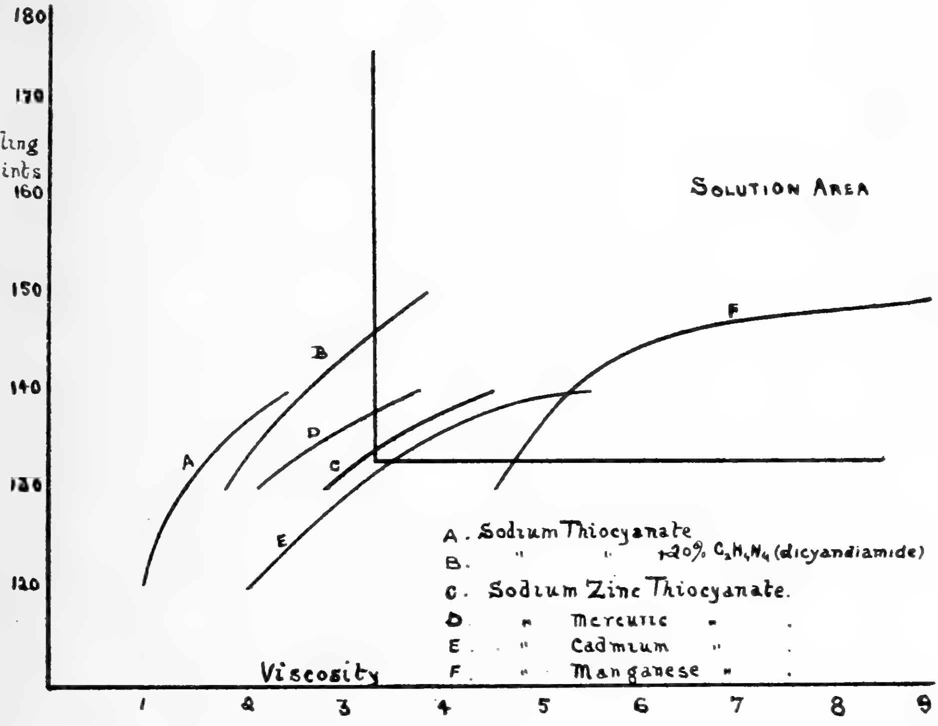


Fig. 3.

This difference between the sodium and potassium thiocyanates and their double salts is very clearly shown in *Fig.* 2. The negative heat of dilution of the potassium thiocyanate solution becomes larger and larger as the concentration increases, but with the solution of the sodium salt it becomes less and less negative, and finally positive.

The solution of the sodium thiocyanate fails to become a cellulose solvent because of its low viscosity, and likewise the potassium salt for the same reason, and also on account of its negative heat of dilution.

The addition of other salts that will either not affect, or will increase the heat of dilution, and at the same time increase its viscosity, should convert the solution of the sodium salt into a cellulose solvent. In *Fig.* 3 the viscosities and boiling points are plotted of the sodium thiocyanate solution to which has been added other thiocyanates and compounds, and it will be noticed that in all cases the addition has increased the viscosity of the sodium salt solution, and the curve passes into the area marked "cellulose solvent area." All these solutions represented by the curves that cross into the " solution area " are cellulose solvents, and moreover they only become solvents when the concentration of the solution rises to the point where the viscosity boiling point curve crosses the " solution area " and above. A very large number of such additions can be made to the concentrated sodium thiocyanate solution besides those given in the figure, such for example as aluminium, chromium, or ferrous thiocyanate, or by dissolving silver, lead, calcium, or cuprous thiocyanate in the solution. All these additions increase the viscosity of the solution, and at the same time convert the sodium thiocyanate solution into a cellulose solvent.

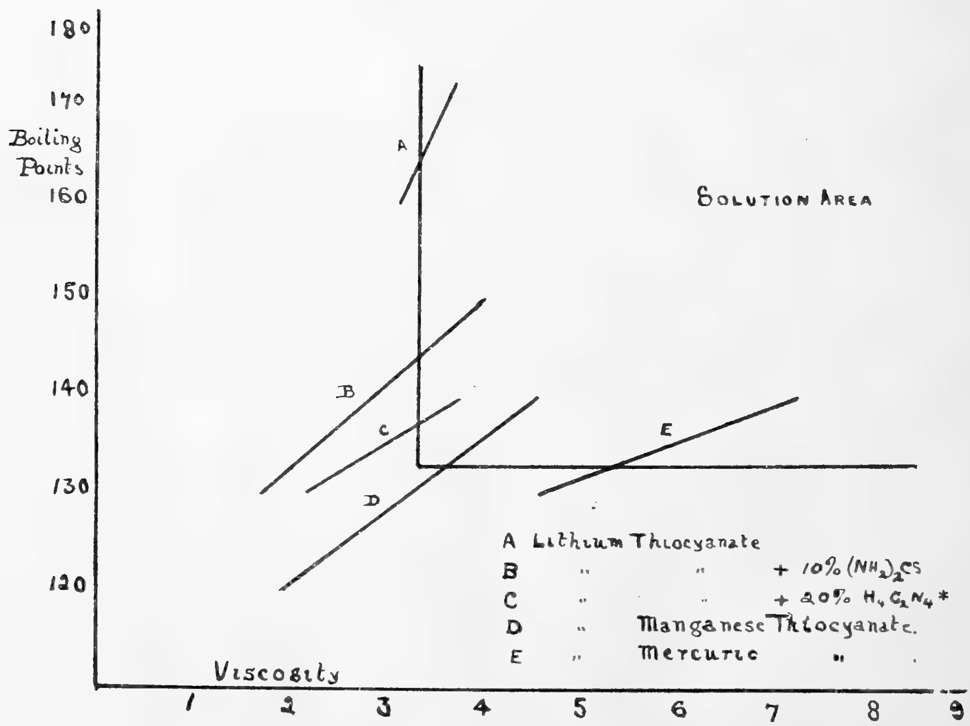


Fig. 4. * Dicyandiamide.

Additions to the potassium salt solutions to increase its viscosity do not, however, produce cellulose solvents, though higher boiling points and viscosity results; for all these mixtures so far examined have, unlike the corresponding sodium thiocyanate, a large negative heat of dilution.

Again lithium thiocyanate solution does not become a solvent for cellulose until concentrated to a boiling point of 165° C., the viscosity being too low for all concentrations below this boiling point. If the conclusions arrived at above are correct, it should be possible to lower the concentration at which the solution becomes a cellulose solvent by additions, which, while not diminishing its heat of dilution, will yet at the same time increase its viscosity. This may be accomplished by a variety of substances, such as other thiocyanates of characteristic viscous solutions as for example the manganese, calcium or aluminium thiocyanate. The addition, however, need not be a thiocyanate for thiourea, hexamethylenetramine, or diycandiamide may be added with like effect. These results are illustrated by curves given in *Fig.* 4.

It is interesting to note that each of these solutions becomes a cellulose solvent at the particular concentration represented by the point where the boiling point viscosity curve cuts into the solution area. Lithium thiocyanate solution does not dissolve cellulose until it is concentrated to a boiling point of 165° C.; but when the viscosity of the solution is increased by additions of other soluble compounds, a cellulose solvent may be obtained boiling 30° C. lower. Each of these solutions has a positive heat of dilution when concentrated.

It is thus seen that whatever the explanation may be there is a definite connection between the boiling point, the viscosity and the heat of dilution of a solution of a neutral salt, and its solvent power for cellulose. This relationship has been very strikingly demonstrated in the course of this work on the thiocyanates, for every thiocyanate either singly, or in conjunction with one or more other thiocyanate solutions, has been converted into a cellulose solvent, although the components of these mixtures may not of themselves dissolve cellulose. In each case, however, it has been necessary to bring the viscosity, heat of dilution, and boiling point within the limits stated above, either by concentrating the solution, or by additions of other thiocyanates either soluble or insoluble—the latter being soluble in the concentrated solutions of the soluble thiocyanates.

These facts apply not only to the thiocyanates, but to all other soluble salts, a number of which have been examined in this manner. Both calcium chloride, and magnesium chloride solution when concentrated to the required viscosity have too great a heat of dilution to dissolve cellulose. Additions therefore which lower the heat of dilution, and either increase, or do not lower the viscosity should convert these solutions into cellulose solvents. This may be accomplished by dissolving mercuric chloride in these solutions, to form the double calcium mercuric chloride, and the magnesium mercuric chloride respectively. By this means the viscosity is increased and the heat of dilution greatly reduced, and the concentrated solution of either of these two double salts dissolves cellulose.

It may here be remarked that the figures given above refer only to neutral solutions, but if the solutions are made acid by a weak acid such as acetic acid, the cellulose is more readily dissolved, and in much greater amounts. If, however, the solution is made alkaline, no solution of the cellulose takes place; for example, if the solution of the calcium thiocyanate is made basic with a little calcium hydroxide, or the strontium salt solution with strontium hydroxide, the solvent action on the cellulose is entirely arrested; this is true for all the thiocyanates, and probably also for all salt solutions.

The concentrated solution of the calcium thiocyanate, which has been more deeply studied than the other salts, not only dissolves cellulose but also dissolves acetyl-cellulose, natural silk, and gelatine; but has no action on wool. The hydroxides of calcium, lead, zinc, cadmium, cobalt, nickel, ferric iron, and stannic tin are all soluble in the concentrated solution. Both the stannic and the ferric hydroxides only begin to dissolve when the thiocyanate solution is concentrated until the composition of the solution corresponds with the liquid hydrate $Ca(CNS)_2 10H_2O$. This is the lowest concentration that will dissolve cellulose. The curves representing the percentage of these hydroxides dissolved in the cold for different concentrations of the calcium thiocyanate solution are given in *Fig.* 5, where it will be noticed that they all take a sharp upward bend from the point where the composition of the solution corresponds approximately to the formula $Ca(CNS)_2 10H_2O$.

That these hydroxides pass into colloidal solution is shown by the colour of the ferric hydroxide solution which is deep brown, showing no trace of the red colour of ferric thiocyanate. All these hydroxides are completely precipitated on dilution.

It is an interesting fact that ferric hydroxide while soluble in the calcium, strontium, and magnesium thiocyanate solutions, all of which are cellulose solvents, is insoluble in the potassium thiocyanate, and calcium chloride solutions of any concentration, both the latter solutions being also non-solvents for cellulose.

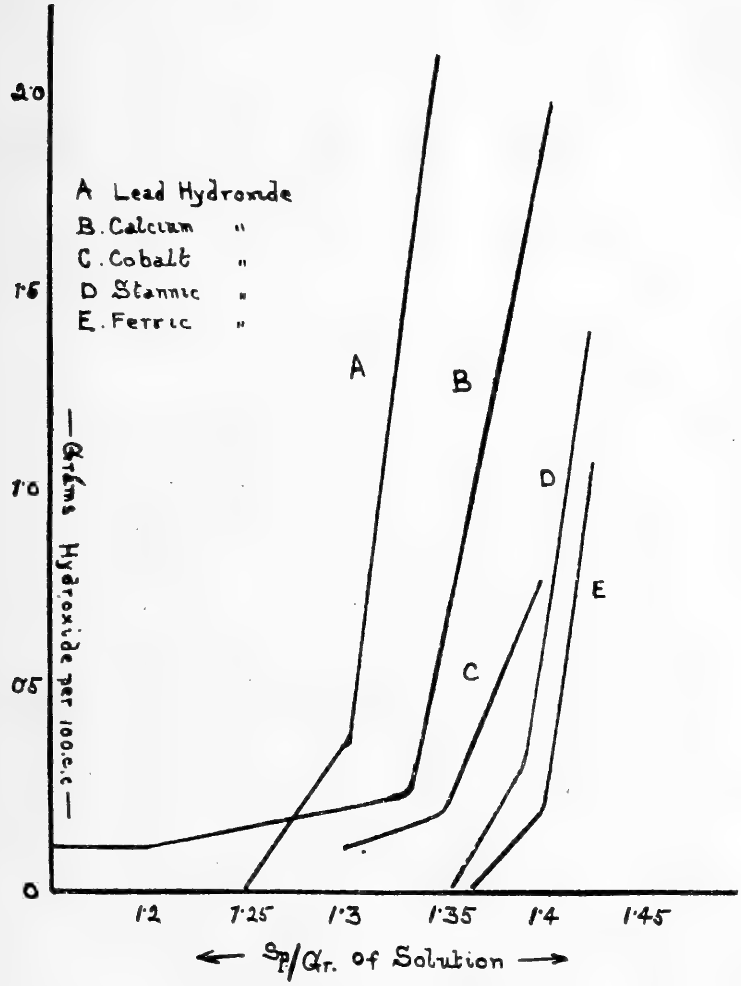


Fig. 5.

Lead sulphate and tricalcium phosphate are also soluble to a limited extent in the concentrated solution, while certain water soluble salts such as sodium chloride and potassium chromate are insoluble. In the light of the above facts, it is evident that one of the main conditions of a cellulose solvent is, that not only must the salt combine with water to form a definite hydrate in solution, but that the solution must be so concentrated that it is capable of combining with more water; the solution therefore at least in the cold must consist of a liquid hydrate.

As an aqueous salt solution having the necessary viscosity and boiling point, but which is not hydrated or only partially hydrated in solution, and therefore contains free water, is a non-solvent for cellulose, it is evident that the combined water plays an important part in the solution of the cellulose, the solution being brought about by means of the combined water, or the capacity of the salt for taking up water. The combination of the salt and water must, however, be of a certain order, that is to say the water must be bound to the salt between the limits of a maximum and minimum intensity, above or below which no solution of the cellulose can take place on heating.

A simple and possible explanation of the solvent action on cellulose of these salt solutions, which fulfils the prescribed conditions, may be stated thus:—The hydroxyl groups of the cellulose unit link up with the salt complex in place of the water molecules, acting in the manner of a substituted water group, thus causing the fibre to swell considerably. The cellulose unit is brought by this means into molecular range with the water molecules combined with the salt. By raising the temperature the union between the salt and water molecules will weaken and tend to part from the parent molecule. The water thus freed migrates to the cellulose by which it is imbibed, causing further swelling of the fibre, which increases as the progressive hydration proceeds. The highly swollen fibre in the gelatinous condition then peptises, and passes into colloidal solution.

The temperature of the solution would in the first place tend to weaken the union of the cellulose aggregate, and in the second place tend to dissociate the salt hydrate complex.

The minimum temperature of the boiling point of the solution is probably not a direct function of the solvent action, but, as it has been shown above that in the liquid hydrate required the water must be bound to the salt between the limits of a maximum and minimum intensity, it is probable that the latter would occur at the same boiling point with various solutes.

The explanation of the mechanism of the entrance of the cellulose into the salt hydrate complex, by means of its hydroxyl groups taking the place of the water, has some other facts to support it. Thus ethyl ether which may be considered as water in which two hydrogen atoms are replaced with two ethyl groups, is practically insoluble in water, and in calcium thiocyanate solution up to a concentration of Sp. Gr. 1.36 which corresponds with the hydrate

$$Ca(CNS)_2 10H_2O,$$

but dissolves in increasing quantities in the cold solution of greater concentration. With a solution of Sp. Gr. 1.4 corresponding to the hydrate $Ca(CNS)_2 8H_2O$ nearly an equal volume of ether is dissolved, and moreover it is a remarkable fact that the amount of ether dissolved is equivalent to the water lost from the decahydrate, molecule for molecule. The amount dissolved corresponds to the formula

$$Ca(CNS)_2 8H_2O 2(C_2H_5)_2O.$$

Conclusion.

The solution of cellulose in an aqueous solution of a neutral salt is independent of the chemical nature of the salt, but is largely dependent upon the physical properties of the salt solution. For such a solution to dissolve cellulose it must consist of a liquid hydrate—an associated molecular complex of salt and water. But this complex must be of such an order that it has a viscosity above a certain minimum, and a positive heat of dilution between well defined limits.

These limiting conditions will vary according to the nature of the cellulose, and the treatment which it has previously undergone; but for any particular cellulose the limits will be constant for all salt solutions in water.

Our thanks are due to the Renwil Syndicate for permission to publish this work, to Mr. C. F. Cross for the kind interest he has taken in this research, and to Dr. H. F. Coward for reading through the paper before publication.

Since this work was accomplished, our attention has been drawn to the work of Dubosc (**1**) in France and of P. von Weimarn (**2**) of Russia.

Dubosc claimed the solution of cellulose in the aqueous solutions of sodium and potassium thiocyanate. Working on the method described in the course of this paper no solution of the cellulose was obtained in either sodium or potassium thiocyanate solutions; and such a solution seems unlikely under these conditions, at least for an unmodified cellulose.

P. von Weimarn in a German patent claims the action of the aqueous solutions of all neutral salts on cellulose, such, for example, as sodium sulphate, potassium chloride, and also such sparingly soluble compounds as calcium sulphate and calcium hydroxide; he also mentions the thiocyanates amongst the numerous examples he gives.

Neither of these investigators mentions any specific concentration, or viscosity, or any limiting conditions for obtaining the cellulose solution.

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Manchester Memoirs, Vol. lxv. (1921), *No.* **13**

XIII. The Problem of Megalithic Monuments and their Distribution in England and Wales.

BY W. J. PERRY, B.A.

(Read February 22nd, 1921. Received for publication September 20th, 1921.)

In a paper published by this Society in 1915, under the title of "The Relationship between the Geographical Distribution of Megalithic Monuments and Ancient Mines," I argued that the distribution of megalithic monuments in different parts of the world would suggest that their builders were engaged in exploiting the mineral wealth of the various countries and in searching for pearls. I stated, further, that gold was evidently the most desired substance. Since this paper was written much confirmatory evidence has come to light. In 1916 Major Munn wrote to Professor Elliot Smith and myself to say that he had been aware of the relationship between megalithic monuments and ancient mines in Hyderabad ever since 1908; for in the course of his duties as Inspector of Mines to the Nizam of Hyderabad he had noticed that stone circles and dolmens were invariably situated close to mines of gold, copper and iron. Major Munn published the results of his investigation in Hyderabad in the Proceedings of this Society (**14**).* In my own work on "The Megalithic Culture of Indonesia," published in 1918 by the Manchester University Press, I have shown that the distribution of megalithic monuments in Indonesia corresponds to that of the sources of gold and pearls. In 1919 Capt. Chinnery published in the Journal of the Royal Anthropological Institute an article entitled "Stone-Work and Gold-Fields in British New Guinea," in which he stated that all the relics of a bygone past that are to be found in that part of the

* I should like here to acknowledge the help and advice that I have received from Mr. J. Wilfrid Jackson, of the Manchester Museum, in the preparation of this paper, as well as the help that Mr. W. H. Corkill has given me in preparing the Maps.

world, stone circles, stone pestles and mortars, stone implements, all of them unknown to the natives of the present day, are located in auriferous gravels or near to pearl-beds. He further states that the natural surroundings of the gold-fields, situated as they are in inhospitable mountain country, are such that only some powerful incentive would impel men to brave the difficulties to be experienced in living there. In my forthcoming work on The Children of the Sun, I propose to present maps of the distribution of megalithic monuments in the Pacific, and to show that the distribution of these structures agrees closely with that of the pearl.

It is thus evident that support has been forthcoming for the theory from various quarters. But much remains to be done in the matter. It is not necessary to be content with the establishment of the theory that the builders of megaliths were seeking for some form of wealth. It is necessary to see if the study of these distributions of ancient mines and megaliths cannot be used for the improvement of geographical method. For the distribution of megalithic monuments is a fact in human geography, and this distribution has to be explained. It is possible that in explaining this fact we may be put in the way of explaining others and thus of helping to build up a science of human geography. I propose in this paper to remember this; and in trying to establish the relationship between the geographical distribution of megalithic monuments and ancient mines still more securely, shall keep in mind the wider bearings of the problem.

Megalithic monuments are closely connected with the working of metal. For in some regions objects of bronze have been found in connection with them. They were made in this country at least a millennium after bronze was first used in the ancient East. Since the building of megalithic monuments is now admitted on all sides to have been derived from the ancient East, it is legitimate to claim that the builders of these monuments knew of bronze, even if they did not leave objects of that metal behind them in every case. In "The Megalithic Culture of Indonesia," a work which deals largely with the cultural associations of the building of megalithic monuments, it is shown that the use of stone only occurs in definite cultural circumstances, and that it is not taken up here and there sporadically just because the stone is lying about. I hope during the coming session to put before the Society further evidence in support of this contention. It can be argued with much force that the use of stone for purposes of construction is only found in this country under the influence of cultural streams, emanating from the Mediterranean, and that the presence of stone has had no causal effect in the matter, seeing that igneous rocks have been transported for unknown distances to make Stonehenge. It can, moreover, be shown that the use of stone for megalithic monuments is confined, the world over, to metal-working peoples, or to peoples who have directly derived their culture from such peoples. This all harmonises with the contention of Elliot Smith that the working of stone only came into being after the invention of the copper chisel. Monuments of unhewn stone would be due simply to that cultural degeneration that tends to set in when the original focus becomes remote in space and time. These considerations support the contention that the megalith builders of England and Wales were actually metal workers or searchers after the metaliferous ores, even if they show no signs of being so from their remains. The only way to put such a contention to the test is to find out if the megalithic monuments were situated in mining districts and in no others. If that be so, then the contention will be enormously strengthened, if not made into a certainty. For, given that the distribution of megalithic monuments agrees with that of ancient sources of metals of various kinds, then it is beyond any probability that any other cause could have been at work, for no other natural circumstance, such as height of land, climate or anything else, has the same distribution as the mineral deposits of this country. The degree of accuracy to which it is possible to work will therefore determine the degree of certainty with which the theory can be regarded.

A broad survey of the distribution of megalithic monuments in England and Wales shows at once that there is a general agreement between that distribution and the sources of minerals Cornwall, Devonshire, Wales, Derbyshire, Northumberland, and Cumberland were well known to possess various forms of mineral wealth;* and this correspondence is enough to allow of a presumptive agreement with the theory. But there is one very great difficulty that must be overcome before the theory can hope for general acceptance. Those of us who are convinced of the truth of the theory have always felt that the distribution of megaliths in Dorset, Wilts and Oxford demanded explanation, and that this explanation would not be exactly on the same lines as those for the megaliths of Devon and Cornwall. For there are neither minerals nor pearls in

***Sketch Map*, No. 1, based on (**7**) and (**20**).

Dorset and Wilts that could have attracted the megalith builders. In the following statement it will be seen that an explanation of this distribution was not forthcoming because a very simple matter had been overlooked. It had been forgotten that while men were engaged in mining for metals they required articles of flint for their everyday life. The

Sketch Map No. 1, showing localities where Megalithic Monuments are found in England and Wales.

recognition of this fact suggested the homely explanation of the localization of Stonehenge, Avebury and the other megaliths in their neighbourhood. Moreover, it has also opened a new door in the study of human geography which seems to promise to lead to the correlation of the various aspects of the life of a community and the observation of the varying influences in the distribution of population.

A study of the map of England and Wales at the present day shows that the population is concentrated most densely in those places where the most desired sources of wealth are to be found. Most of our population is concentrated on the coal-fields and iron-fields, on which our civilisation is founded. So in former times people settled where they found the materials that were necessary for their existence.

Sketch Map No. 2, showing the geographical relationship between the distribution of Megalithic Monuments and the Granite areas of Devon and Cornwall.

It will be well to begin with the region where megaliths are most numerous, on the supposition that where people are most thickly concentrated their intentions will be most apparent. *Sketch Map* No. 2 shows the distribution of dolmens and stone circles in Devon and Cornwall (**19**. *See Map*). They are, with a few exceptions, enclosed within certain areas that are defined on the map. What are these areas? They are those of the granite formations of these two counties. What possessed the megalith-builders to choose granite formations on which to settle? They must have had some good reason for choosing these areas and ignoring others probably just as suitable, Exmoor for example. The solution that I wish to suggest is as follows. A former director of the Geological Survey makes this statement with regard to these granite areas. "Granite, or its modification elvan, occurs near, or at, all the localities where tin and copper so abound as to be worked and produce good mines, while lead, antimony, manganese, iron, and zinc are discovered in sufficient quantities to be profitably raised at a distance from granite or elvan" (**2**, 285-6). I suggest, therefore, that the megalith-builders in these areas were seeking and working some mineral. The two most likely possibilities are gold and tin, both of which occur in all these areas (**10**, 58*e.s.*, 3, 70). Of course there is but little gold left now, and much of the tin is exhausted, but there is good reason for concluding that gold must have in the past been much more plentiful than at present in these areas. It is well known that gold was used in the Eastern Mediterranean from the beginning of neolithic times, so it is natural to find that our country was apparently sought out by men who were attracted by the lure of the gold it contained. The history of California, South Africa and Australia during the past century show with the utmost clearness the motives that lead men from civilised countries to those that are not civilised. The prime cause of such a movement is not the desire to cultivate the land, but to seek wealth. Apparently the men of these days were bitten by the same motive. So we can account for the presence of megalith-builders in Britain by the assumption that they came after the gold and settled in greatest numbers where they found it.

It is possible that the gold-hunt had an important consequence. For, throughout Europe, France, Spain, England, Ireland, and elsewhere, gold occurs in close conjunction with tin, for both proceed from the same geological formations and both have approximately the same specific gravity. The men who were washing the gravels of Dartmoor for gold could not fail to find the tin that existed there. Thus in the various parts of Europe where there is a common distribution of megalithic monuments and gold-washings, such as Spain, France, England, Ireland, there is the possibility that tin was first discovered. The working of tin for the manufacture of bronze would attract men perhaps even more than gold. At any rate it is legitimate to conclude that the men who washed the gold of Dartmoor were also extracting the tin and taking it back to the Eastern Mediterranean in order to make bronze.

An apparent exception is of particular value for testing a theory. We are fortunate enough to possess one in the case of St. Austell Moor. This is the most important tin-washing area of Cornwall. The geological formation is granite. Why therefore were not the megalith builders working the tin that existed there? Surely if they were so keen for gold and tin they would have hit upon this obvious spot, teeming as it was with the minerals that they so desired? It may be claimed that megaliths once existed there, but that they have been destroyed. That may be so; but the fact that St. Austell Moor is now the most prolific source of tin in Devonshire and Cornwall suggests rather that the megalith-builders never found it out at all, and that the supplies tapped in modern times were practically virgin. The places where the megalith-builders settled in numbers, Dartmoor for example, are almost bereft of tin, although we know from the presence of tin lodes on the summit of Dartmoor* that stream tin must have existed there in the past in great quantities.

Mr. J. Wilfrid Jackson, of the Manchester Museum, has supplied the explanation in this case. He points out that the tin-washing area of St. Austell Moor is that of the source of china clay, the product of the disintegration of the granite. And he suggests that the tin would be left alone by the early men on account of the great depth of superficial deposit of china clay that overlaid them. His views are fully confirmed by the map published in the *Memoirs* of the Geological Survey (**11**, 105, 106, 108, 170, 174, 177, 178), which shows that the tin-lodes occur in the areas covered with deposits of china clay. It is also said that in this region the tin deposits are very capricious, which would constitute another reason why the area should apparently be overlooked.

The theory that the megalith-builders of Devon and Cornwall were attracted to the spots where they settled because of the presence primarily of gold, and secondarily perhaps of tin, accounts without difficulty for the facts. How otherwise can it be explained that St. Austell Moor was ignored while the other granite areas were ransacked? It is well known

* This can readily be seen by a reference to the Geological Survey Map of the district.

that the tin-washing industry goes back in this part of the country for an unknown age. It certainly seems that the builders of megaliths were attracted there on account of their interest in that industry.

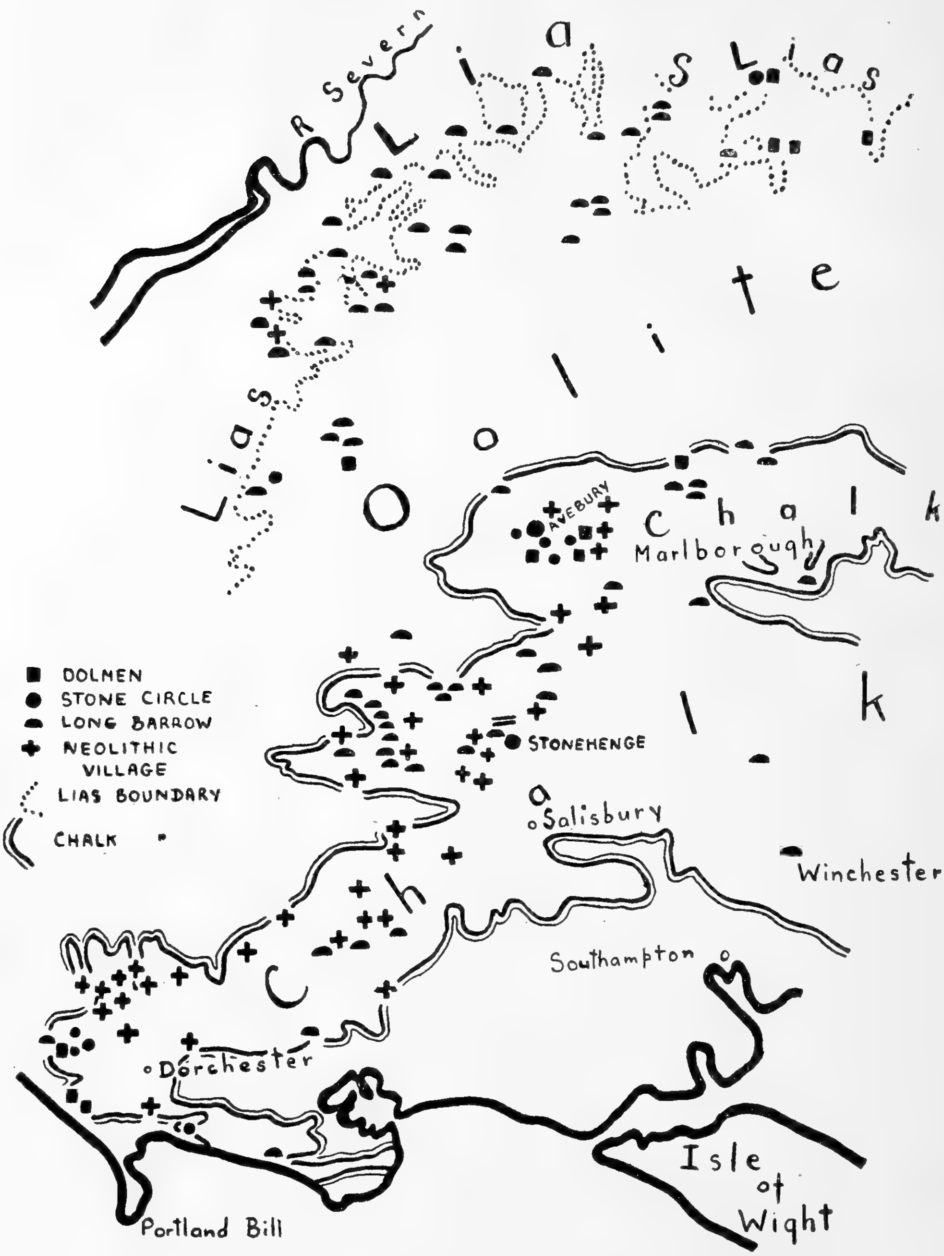
In Devon and Cornwall the megaliths are situated on the granite formations. That is to say, we have succeeded in correlating a geological formation with a group of human remains. By this means it is possible to avoid some great difficulties that beset the inquirer into such problems.

When inquiring into the distribution of ancient mines, it is often impossible to obtain records of these mines, and often difficult, if not impossible, to distinguish between an ancient and a modern mine. The subject of ancient mines has, up to the present, been practically ignored by archæologists, which is strange in a branch of inquiry which deals with the metal-working crafts, and bases so much of its reasoning on the distributions of copper, bronze and other implements and weapons. It is surely a matter of fundamental importance to know the exact sources of these metals; but, so far as I can tell from careful search, the subject, with one or two insignificant exceptions, has been entirely neglected: so much so that a prominent archæologist of this country had occasion only this year to emphasize the necessity for such study (**4**). A detailed inquiry into such matters cannot fail to help on the study of archæology.

The study of the distribution of early mining centres is beset with yet another difficulty. For, if the first metal industry in this country was gold-washing, followed by tin-washing, both for purposes of exportation only, the traces of such exploitation will in all probability have vanished. Later comers would work over the old heaps once again, streams would change their beds, and a thousand and one chances would suffice to sweep away all traces of the old occupation. Moreover, men who were working gold and tin for export would take good care to remove as much of those metals as they could. One does not go to old mining camps to find the metals that are worked there.

The only chance in this case is to find some method that is independent of such caprices of fortune. And it would seem that in the correlation of human distribution and geological formation we have the standard that cannot be upset by any of these vicissitudes. The granite formation of Devon and Cornwall has not altered for millions of years. It has, so far as man is concerned, always been there. If, therefore, we establish a relationship between megaliths and the granite, we are establishing a connection that is independent of any chance disturbing causes. That correlation has to be explained, and on the laws of probability, there is only one possible explanation. Some intrinsic property of the granite must have attracted the megalith-builders. That intrinsic property is the presence of gold and tin. This, coupled with the presence of men who valued those things, would produce the correlation.

This reasoning suggests a method of study of the distribution of any element of human culture. We find that the megalith-builders of Devon and Cornwall settled on the granite. That is to say, the geological formation played some part in determining their presence there. But there is another side to the matter. Given that the gold and tin of the granite was the attracting cause, how does one account for this attraction? It is well known in other parts of the world, Australia, California, and elsewhere, that the mere presence of the metal has no causative influence in the matter at all. Men have lived in these countries for thousands of years and have not paid the slightest attention to the gold. Men have even lived in such regions, and have witnessed the coming of gold-miners, watched them at their occupation, and still not yet learned to value the metal. Apparently, then, there was something in the minds of the megalith-builders that caused them to assign an arbitrary value to the gold, and they could only have derived that knowledge from regions where the metal possessed this purely arbitrary value. The human mind, therefore, in this case, was the real deciding factor: the presence of the gold was merely an accident. If they had not found it in England they would have gone elsewhere. On the basis of the study of peoples of low culture in other parts of the world, it is evident that the first gold-workers of this country must have come from a place where that metal was desired. It would appear, therefore, that one of the ways in which the distribution of civilisation has been effected is by the creation in men's minds of certain desires, and by the efforts to satisfy those desires. We want gold and go where we can find it. So, apparently, did the men of old. They did not work gold just because it existed there. This distinction between the relative roles of the human mind and natural circumstances in the building-up of civilisation is fundamental, and round it centres the conflicts of the two schools of students—those who believe in the growth and spread of culture, and those who believe that it sprang up in response to natural circumstances in different parts of the earth.



Sketch Map No. 3, showing the geographical relationship between the distribution of Megalithic Monuments, Long Barrows, Neolithic Settlements, and the Chalk and Lias Formations,

Having thus established a correlation in one place, it is natural to turn elsewhere to see how the method will work. Going east from Devon the next place where megaliths are found is in the region of Dorset and Wiltshire, where are the most famous megalithic monuments of the country, Avebury and Stonehenge. These have hitherto provided the most serious stumbling-block to the theory. What could have caused men to live there where there is no mineral wealth at all? With the experience gained in Devon and Cornwall in mind, we ask, On what geological formation are they situated? The answer is provided by the map. They are all on the chalk. But it is possible to go still further. For I am informed by Professor D. M. S. Watson, of University College, London, that they are on the Upper Chalk, the part of the chalk formation that contains flints.

Are we then to believe that the megalith builders chose to live on the upper chalk because it contained flint? There is every reason to believe so. It appears that the best kind of flint for the making of implements is that got from layers embedded in the chalk, and not that which lies about on the surface. Flint implements are found in all parts of the country, even in places far away from sources of the material (**6**, 278). Sir John Evans mentions particularly Devon and Cornwall as regions where there is an abundance of flint implements and flakes, and these counties have no flint-bearing formations, though in some places there are some on the surface (**6**, 126 *e.s.*). Those would not be nearly so good for the purpose as those from the chalk regions of Wilts and Dorset. We have thus the remarkable fact that flint implements are found all over the country, and that the builders of megaliths, including long barrows, have chosen out those very parts of the chalk country which produce flint.

It is a commonplace of economics that population is attracted to the centres of manufacture. The great importance of flint in the days when megaliths were made would make its manufacture of implements a considerable part of the economic life of the people living there, temporarily or permanently. The great concentration of neolithic villages, long barrows and megaliths on the upper chalk, therefore, is well in harmony with other facts. The flint manufacture was of primary importance to the people of those days, and they settled where they could get flint. How otherwise can we explain the peculiar distribution of man on the Downs of the South of England? Many hundreds of square miles of Downs are entirely devoid of signs of habitation in these days, no traces of neolithic villages, long barrows or megaliths having been found. Yet all the natural conditions, with one exception, are similar. The presence or absence of flint is the only varying factor, and it is with this factor that I associate the settlements.

It is on the basis of the theory that the presence of megalithic monuments is determined by the presence in the place of some desired substance that it is possible to account for the group of megaliths in Kent, especially the dolmen of Kit's Coty. This dolmen is situated close to a flint-producing chalk-pit.

The great concentration of remains along the margin of the chalk, accompanied in many cases with cultivation-terraces on which the people grow their food, helps to put the great remains of Avebury and Stonehenge into their right setting. Large flint workshops have been found at Avebury, the most important megalithic monument of this country. An all round the people must have been engaged in making the every-day implements of flint that were scattered subsequently all over the country, just as the products of Birmingham find their way broadcast.*

The inquiry has now put us in possession of two correlations between geological formations and megalithic monuments. It has also brought up into prominence the every-day arts and crafts which, as we know from our modern experience, play so important a part in influencing the distribution of population once a settlement is made in a country. I do not pretend that the builders of megaliths came to this country to settle in chalk regions. That probably happened after they had become firmly established in the mining regions, and as the result of their need for tools to carry on their various industries, which would be of the form and of the materials to which they were accustomed at home.

The results already obtained enables us to inquire of other

* It is interesting to note that another place noted for the great size and number of its megaliths, the Orkney group, probably owes its megaliths to the presence of flint. The boulder-clay or this group, I am informed by my friend, Mr. Hopwood, of Manchester University, contains many flint nodules. Flint is rare in Scotland, being confined apparently to the boulder-clay of the northeast region. We know that flint flakes abound in the Orkneys (Evans, *op. cit.*). The presence of important settlements in flint-producing regions, gives an idea of the significance of this homely material in the study of human geography. Sir William Boyd-Dawkins, in his "Early Man in Britain," says: "It is obvious, from the existence of centrés of mining and of manufacture, that the Neolithic tribes of Britain had commercial intercourse with each other. The implements were distributed over districts very far away from the places where they were made" (p. 280). And again: "Stone axes were distributed over areas far away from those in which the stone was found" (p. 290).

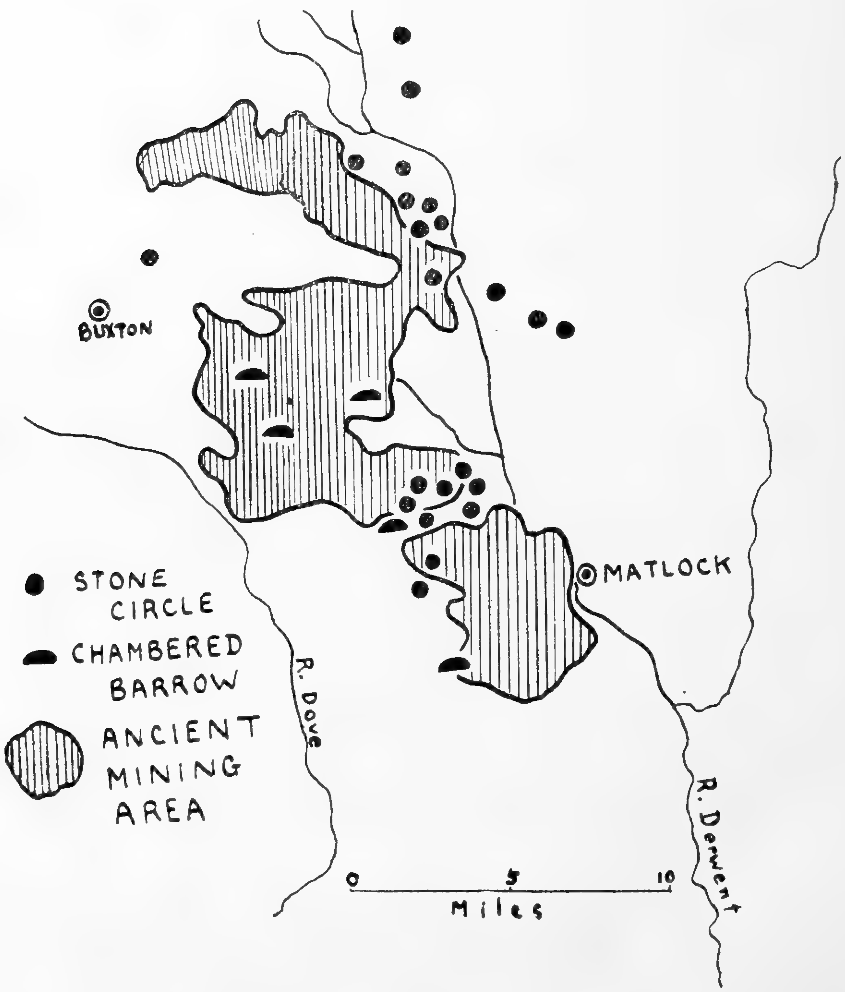
groups of megaliths. On what geological formation are they situated, and why are they on those formations?*

Apparently the need for flint to make implements led some of the megalith-builders to settle on the chalk. Had they any other domestic needs? An examination of the classical work of the late Sir John Evans on "Ancient Stone Implements," shows that the people of the megalith-building age made ornaments of jet, kimmeridge shale, amber, and perhaps even of ivory and gold. They painted themselves with pigments of ochre, hæmatite and ruddle; they placed quartz and other pebbles in their graves; they used iron for pigments and for firelighters; they made implements of other stones than flint, chiefly of basic rocks, quartzite, ironstone, greenstone, hornblende-schist, granite, mica-schist and so forth. Just as the flints have been carried to parts of the country where the stone does not occur, so all these substances are found far away from their places of occurrence. For example, a celt has been found at Newton (Lancs.), made of a fawn-coloured slate like that of the Snowdon region. Hæmatite from Lancashire or Westmoreland has been found in a barrow in West Kintyre (**6**, 26, 96, 118). Jet was widely used in those days. The search for it will account for the stone circles near Whitby, the most famous source of the substance in this country. It is quite possible that the pearls of the Esk River also attracted these people. If we examine the group of megaliths of Oxford we find that they are on the margin of the Lias formation. There is also a close relationship between long barrows and the Lias. Why should the long barrow people have chosen this region? In the case of the megaliths of Oxford it is to be noted that they are just at the south end of a great ironfield running up as far as the Clevelands. The *Memoir* of the Geological Survey states that there are important surface iron-workings in the Middle Lias formation of Oxfordshire, generally of brown hæmatite, although it is said that red hæmatite is found in certain spots, but the places are not mentioned. These surface workings are mentioned at Fawler, Adderbury, Hook Norton, Woodstock, Steeple Aston, Banbury, all of them close to the megaliths. Again it is said that

* Before developing this theme any more, it will be interesting to note that Mr. Crawford has already published a map (*Journ. Roy. Geographical Soc.*, 1912, **40**), which shows that certain finds of the early bronze age in this country are closely confined in the Fen district to the margin of the chalk. This is a case of a correlation between a geological formation and the distribution of an element of human culture.

"iron pyrites and marcasite are found more especially in the Lias shales. They are most abundant in the shales of the Lower Lias" (**21,** Chap. XL). So this formation contains things that these early people required for their personal adornment and other purposes. In view of the difficulties of the geological problems involved I do not propose to do more than draw attention to the relationship between the megaliths and the Lias formation, and to suggest that the occurrence of iron, ochre, shale and so forth in this formation may have been the cause of the association.

Mr. Crawford has already been quoted as calling attention in the *Geographical Journal* to the direct association between the remains of the early bronze age and the chalk margin of



Sketch Map No. 4, showing the geographical relationship between the Stone Circle and Long Barrows of Derbyshire and the area of Ancient Mining.

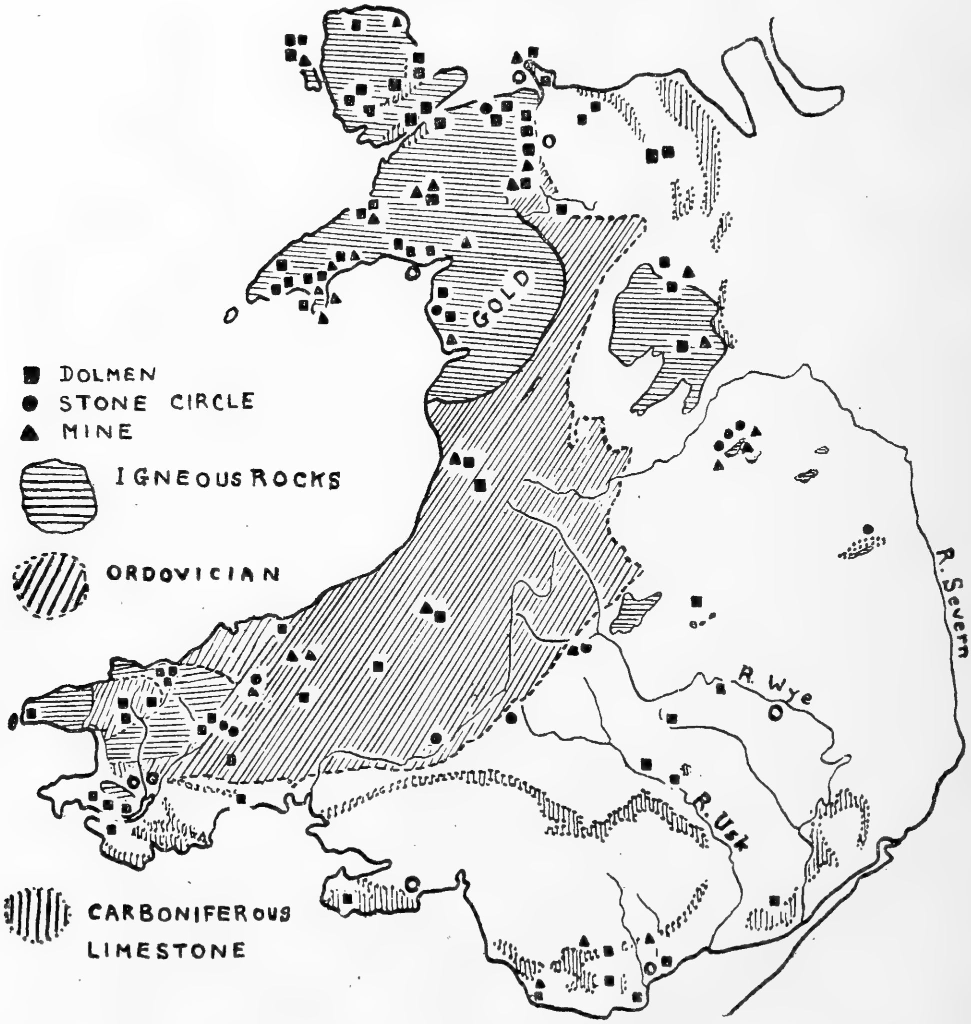
the Fen district. He states further in the same place that in Derbyshire a line drawn on the map representing the boundary of the carboniferous limestone practically encloses all the early bronze age finds, in the shape of beakers and celts, of that county (*op. cit.*, 183). It is possible to go still further and to state that the same line includes almost all the stone circles and chambered barrows of that county. On *Sketch Map* No. 4 I have traced out the area occupied by ancient mines in Derbyshire according to the "County History." It is evident how closely it agrees with the distribution of the stone circles, and the chambered barrows of the neolithic age. As in Devon and Cornwall, it is hard to resist the conclusion that the makers of these monuments were miners. In this case the mineral sought for was lead, which occurs in the carboniferous limestone in all parts of the county. Plenty of surrounding districts were apparently equally suitable for occupation, but the megalith-builders do not seem to have been attracted to them.*

This discussion has now ranged over the southern part of England, and uniform results have been obtained. We have succeeded in establishing a direct association between the distribution of megaliths and certain geological formations. In Devon and Cornwall the geological formation in question was granite; in Dorset and Wiltshire it was chalk with flints; in Oxford it was the Lias; in Derbyshire the Carboniferous Limestone. In the North Riding the stone circles are associated with the Lias in which occurs the jet that was so highly prized. This association between two distributions enables us to account for such remains as Kit's Coty House, near Maidstone, near which there is a large flint quarry.

It is important to note that the concentration of megaliths on the chalk is on the western margin. A glance at *Sketch Map* No. 6 shows that there are other patches of the chalk rich in flint. How is it, for example, that there was no greater concentration round Brandon where were the famous Grimes' Graves, those mines for flints, and near Cissbury, where mining was also going on for flints? The answer seems to be that the attention of the megalith-builders was mainly

* The question naturally arises as to why they needed the lead. In later times in Britain silver was often extracted from it. Lead and silver were used in the Near East at a very early date, and it is quite possible that the builders of the long barrows and stone circles were exploiting this form of wealth. On the other hand, the galena may have been put to some other use, for example, as a pigment.

directed to the west, where they found gold, tin and other minerals, and that they supplied themselves mainly from such sources. The great concentration along the western margin of the chalk certainly suggests this explanation, and thus constitutes another reason for concluding that the search for certain minerals was the prime concern of the megalith-builders, and that the flint industry was located in the nearest possible region to the sources of these minerals.



Sketch Map No. 5, showing the geographical relationship between Megalithic Monuments and Mining Areas in Wales.

It is now necessary to turn to another region, that of Wales. This country contains much mineral wealth, and thus it would be expected that the megalith-builders settled there, and especially in those parts that were rich in minerals. On the map the regions that are metalliferous are distinguished from those that are not usually so. I have not found it possible to trace any attempt to work out the distribution of ancient mining centres in Wales. Much research has been lavished upon the megaliths, but the mines have been almost entirely neglected, except for a stray monograph such as that of the Hon. Owen Stanley upon Holyhead (**18**). So I have adopted the device of marking in the metalliferous formations and known mining sites that are recorded in the *Memoir* issued annually by the Geological Survey.* The triangular spots represent mining sites, whether ancient or modern. In the Ordovician region I have not attempted to mark all that are known, but have put them in chiefly with reference to the situation of megaliths. On the other hand I have marked all the sites that I could find in the non-metalliferous region. The indication of a mining site does at least tell us of the presence of lead or copper in the neighbourhood, and that is enough for our present purpose. It is quite certain that much information of this kind remains to be collected in Wales. For example, at Clynnog, there are three dolmens, but I have never seen any mention of mines, ancient or modern. Yet I know personally of one within a mile of a dolmen, and am told locally that there are old copper mines just on the other side of the village, within a mile or so of the other dolmens.

A cursory examination of the map shows that the great majority of the dolmens and stone circles marked on it are in close proximity to mining sites, mostly lead, but some of them copper and gold. This is particularly noticeable in Carnarvon, where there are old mining sites, particularly near Snowdon. The dolmens are distributed thicked there than in any other part of the country. It will be noticed that the vale of Conway is particularly full of dolmens. There are also mines there, and this would account for them. But there is another possible reason. The Conway is famous for its pearls, both the fresh-water and the salt-water pearl-bearing mussel being there. So it may be that the presence of pearls attracted the dolmen-builders there just as it did the Romans. This explanation would also serve to explain the presence of dolmens round Criccieth and Portmadoc, for in both these

* (**12**). Some cases are derived from the Memoirs dealing with the various sheets of the Geological Survey Maps.

regions fresh-water pearl-bearing mussels are reported.* But here again one must be prepared to hear of the presence there of other forms of wealth that attracted the megalith builders. Near the Conway valley are some stone circles and dolmens situated at the back of Penmaenmawr. Till recently I was of the opinion that these monuments were connected with the people of the Conway valley. But it appears that they can be brought rather into line with settlements of the nature of those of Wiltshire. For recently there has been examined an important factory of stone implements on Penmaenmawr, whence implements were exported, at least as far as Anglesea. Apparently old copper mines have been found in parts of North Wales, on Snowdon, on Great Orme's Head, and in Holyhead and Anglesea (**18**). In the tiny island of Holyhead there are several dolmens. In the middle of the last century the Hon. Owen Stanley examined some of the ancient hut dwellings that exist there. He found large pounding-stones, saddle-querns, rubbing-stones of grit that must have come from the middle of Anglesea, whorls of buttons, and hammers. From the similarity of their implements he concludes that the people all over Holyhead and Anglesea must have been engaged in the same industry (**18**, 9). Speaking of Plas Penrhos or Plas Milo, he says that a copper vein runs near the ruins of the circular huts that have been found there. He also mentions several standing stones in the near vicinity. These remains must also have been quite near to the dolmens of the island. Mr. Stanley says that the fire-places that have been found in the old Holyhead settlements are "so disposed and formed as to suggest the supposition that they may have been for the purpose of heating and working metal rather than for cooking, the slag and clay-lined fire-place, as I have supposed them to have been, the stone mortars, the pounding and grinding stones also strongly embedded in the floor of the huts, the broken quartz from the copper lode, and the close proximity of both copper and iron ore," all suggesting metallurgy. He goes on to say that in the opinion of a competent geologist and mineralogist, Sir Richard Griffith, it could not be doubted that some extensive works had been carried on; but . . . .

* (**8**). *Cf.* J. W. Jackson. "Shells as Evidence of the Migrations of Early Culture." I am indebted to Mr. Jackson for information with regard to the existence of pearls in other parts of Wales. For information with regard to the existence of pearls at Criccieth I am indebted to my friend Mr. Owen Roberts, of Gyrn Gych, Clynnog.

"there was (*sic*) no scoriæ in any quantity, nor, as it appeared to him, the indispensable means and appliances for smelting hard ores; still they might perhaps have worked metal in these huts, or even smelted the soft carbonates of copper usually found on the surface of lodes. . . . . The quantity and large size of many of the pounding and smoothing stones found could not have been for the exclusive purpose of preparing food; these appliances must have been used in some sort of manufacture." (**18**; 10, 17, 18). There are several dolmens on the island, but it is not possible to demonstrate that the dolmen-builders made the huts. But the culture of the hut-builders was so similar to that of people of the age of the dolmen-builders in other parts of the country that there can be little doubt about the matter. The concentration of dolmens in Holyhead and Anglesea seems to be best accounted for by concluding that the dolmen-builders came there on the same errand as the hut-builders, even if they were not the same people, *i.e.*, that they were miners.

As regards the Lleyn Peninsula, I am much indebted to Professor Stopford for information with regard to old lead mines there, and the distribution on the map is founded on information derived from him. In Merionethshire there are dolmens and stone circles in a region that contains ancient mines, and also is near to an important goldfield. Elsewhere in the Ordovician region are scattered dolmens, often associated directly with a modern mine.

Pembrokeshire presents a somewhat elusive problem. For, in spite of the great extent of its igneous rocks, there does not appear to be any great amount of mineral wealth. There is a notable concentration of dolmens round Milford Haven and the Clyddau river. This river is the home of pearl-bearing mussels, and this may have constituted the attraction. But on the banks of Milford Haven there are also factories of stone implements where the dolmen-builders may have been engaged in making stone implements. At the eastern end of the Preselly Mountains there certainly are minerals, in the form of silver-lead, and again at Newcastle Emlyn there are lead mines. It seems that in this county we have to turn to a variety of explanations for the distribution of dolmens, but must attach chief importance to pearls. It is significant that the hypothesis of the search for pearls affords an explanation for so many Welsh dolmens—Conway River, Cardigan Bay, and Pembrokeshire—and in all these cases they are concentrated fairly closely, showing the existence of some strong reason for settlement in such places.

As regards the whole of the Ordovician region, it is beyond doubt that the future will afford more evidence with regard to ancient mining. The matter has as yet hardly been given any thought, but as up to the present the result of investigation has been still further to strengthen the position taken up here, there is not much doubt that the few dolmens that are not definitely linked to a mine or some other source of wealth will in time receive their explanation.

Let us now turn to the region characterised by non-metalliferous rocks, the Silurian and Devonian. Scattered throughout this large region are masses of metalliferous rocks, particularly the carboniferous limestone, so closely associated in Derbyshire with lead. In Denbigh and Flint there are many mines in this formation, and the dolmens are close by. Further to the south the Ordovician turns up again, and we get a dolmen within a short distance of lead mines. Still further to the south is an occurrence of igneous rocks, and a stone circle close to a mine. Further to the south, again, there is a dolmen near to igneous rocks, but not, so far as I know, near to any mine. Then further to the south again there is a stone circle close to a mine. In South Wales there is a series of dolmens close to the carboniferous limestone where there are traces of former lead mining. In the valley of the Wye there are two dolmens apparently far away from any possible source of metals, both of them close to the river bank. This is a pearl river, for pearl-bearing mussels are known near Hereford, fifteen miles or so down stream from the dolmen. So it is possible that the dolmen-builders were pearl-hunting up that river. Apparently there are pearl-rivers all along the coast of South Wales, and that may account for more than one of the dolmens that exist there.

When we get out of regions that are known to be metalliferous the distribution of megaliths becomes more diffuse, and it is often difficult to assign a cause in any given case. The existence of a single megalith may be due to an accidental local circumstance. There could not have been in such a place any strong incentive to settle, or else we should find more than one dolmen or circle. The contrast between Carnarvonshire and the centre of Wales is striking, and it does not seem that any other explanation can be given for the distribution of megaliths than that which is so strongly suggested by the Holyhead evidence, namely, a knowledge of metallurgy and mining on the part of the megalith-builders and a consequent concentration on the mine-fields. At the present moment we find most of the population on coal-fields, but there are other concentrations due to local circumstances, such as the presence of a good clay for pottery, a good soil for hops, or the possession of any of the thousand and one mineral substances that play their part in the civilisation of the country. So, in the same way, we should expect to find the megalith-builders concentrated in those regions where they found what they desired most, and more scattered in other places where the desired object was of less importance or less abundant. The evidence from Wales entirely bears out the contention that the search for certain forms of wealth has determined the distribution of the megalith-builders. We have moreover found that the association with certain geological formations also holds good. This is marked in the non-metalliferous area, where the megaliths are with few exceptions near to metalliferous formations.

To turn now to the county of Shropshire, to the mining district on the border of Wales that lies near Shelve and Minsterley:—What could have possessed the megalith-builders to leave behind them at least three stone circles in such a place? One cannot plead high ground, or suitable soil for cultivation, or a nice climate, or proximity to the coast, or trade routes, or anything of that sort. For, in the words of the author of a monograph on this district: "Shelve is a mining district. The land is poor and profitless on the surface, while the rocks beneath are rich in mineral wealth. The veins of lead have been worked at intervals since soon after the Romans landed in Britain, and they still yield large quantities of ore. When they were first discovered it is probable that the lead was exposed in ridges down the hill sides, for even now the siliceous contents of some of them can be traced along the surface; and between the Grit Mines the Ryder vein forms a projecting wall for several yards. The very early occupation of this secluded spot of England by the Romans shows that they attached considerable importance to its mineral wealth" (**13**, 23). What valid reason is there for not believing the same of the megalith-builders? The soil is poor, the region inhospitable. If it be said that these people were driven westward by invaders, I should ask why they did not hide in the Long Mynd instead of in the country round Minsterley? Such an explanation explains nothing. But if it be agreed that the men who made the circles were lead miners, then we have a rational solution of the problem. We find once again a concentration in metalliferous regions, and an entire neglect of those barren of minerals.

In his work on "Early Man in Britain," Sir William Boyd

Dawkins says that during the Roman occupation "the mineral wealth of the country was eagerly sought, not only for the tin of Cornwall, or the iron of the Weald of Sussex, or of the Forest of Dean, and of the northern counties, but the gold and copper of Wales, the lead of Derbyshire and of Somerset, the jet of Yorkshire, and the coal of Northumberland" (488-9). This is true, and the sooner it is recognised as such by historians the sooner shall we know something of the real cause of the foundation of the Roman Empire. But when we learn that the Romans, in going to Whitby for jet, to Derbyshire for lead, to Cornwall for tin, to Shropshire for lead, to Wales for lead and copper and pearls, found themselves anticipated there by the megalith-builders, who seem to have concentrated on such spots, what rational reason have we for denying to these earlier comers the same desires as those that possessed the Romans? These metals were being used in the Mediterranean thousands of years before the Romans emerged on the scene. What reason have we for refusing to believe that, just as the Romans opened up mines that, after their departure were left idle for centuries, so, in the dim past, some other people had come to exploit the mines, which when they went for some reason or other were also left untouched? We know full well that metals were mined in this country in pre-Roman times, so why should not the megalith-builders have taken a hand in the game?

We must remember that they ignored those parts of the country devoid of things that they used in their daily life or in their industry, and carefully chose out those that contained useful objects.

I suggest, therefore, that the megalith-builders were miners: that they settled in mining regions. Also they made settlements in places where they found materials for their domestic and industrial implements and utensils and for their personal adornment.

This solution is in accordance with our knowledge of modern civilisation. It reduces the problem of the distribution of population mainly to that of determining human needs and of discovering where exist the means for their satisfaction. So human geography goes hand in hand with history and psychology, and each serves to illuminate the other. The pattern made by a population distribution such as that of the megalith-builders reflects the needs of the builders. The needs of the builders once known will enable us to predict where they would tend to settle. Thus we can eliminate climatic and physiographical factors as playing no real causal part, but as tending to modify the distribution in certain circumstances. Man has impressed indelibly his personality upon the face of the earth. He has defied climates such as that of West Africa, on account of the gold that exists there (**9**, 181 *e.s.*); he has frozen in Siberia for the same reason (**17**, vol. ii); he has created great civilisations in the jungles of Cambodia; he climbed the inhospitable hills of New Guinea

Sketch Map No. 6, showing the geographical relationship between the distribution of River Drift implements and the Chalk and subsequent geological formations.

to work the gold gravels of the rivers (3), regardless of disease, danger and all the climatic adversities imaginable. In his desire to get certain objects he has ransacked the whole earth and left vanished civilisations as witnesses to his strength of will when once his desires are fully aroused.

It would seem that in the possession of the principle of the association of certain elements of human culture with definite geological formations we have an implement of research which may help in the determination of the relationships between the economic and political factors in any civilisation. *Sketch Map* No. 6 suggests that men of the early paleolithic age lived mainly in the flint-producing regions where they found the material for their implements. So it is possible that the first act in the drama of civilisation was played out on flint-bearing formations. This relationship between geological formation and human distribution seems to hold in this country down to the time of the megalith-builders. If that be so, it should not be impossible to discover by what means men came to create the needs that led to the inauguration of the neolithic age and to settle on other formations that provided the means of satisfaction of these needs. What led men first into regions containing volcanic rocks that supplied him with material for his polished stone implements? How and why did he create the need that led him on to the carboniferous limestone for lead? Such problems as these will have to be faced and solved.

It is found, however, that the relationship between human distribution and geological formation does not exist in every type of civilisation. In early days the economic factor was evidently paramount, and the pattern produced on the map by man corresponded strictly to the needs of the community. But when we come to consider the distribution of settlements such as those of the Romans, we realise that both political and economic factors were at work; because the Romans made many settlements that were purely strategical, and bore no direct relationship to sources of wealth. In the case of the Romans there was a sort of balance between the economic and the political life of the community which is reflected in the distribution of population. When we come to the Teutonic invasions we find that the distribution of settlements was not determined by causes that were patent in the case of the megalith-builders. Apparently political forces were paramount, and industrial needs mainly neglected.* This diver-

* Or perhaps, as Dr. Haddon suggests, agricultural interest was predominant.

sity of civilisation is not peculiar to Britain. All the world over there have been successions of civilisations markedly different in nature, each showing by their distribution of population the presence of distinct needs. These civilisations, many of them vanished, have often left behind them remains. A study of the distribution of these remains will give us an idea as to the motives of their authors. In this way, by a comparison of results obtained in all parts of the world, it should be possible to help to build up a stable theory of civilisation.*

* Since this paper was read before the Society I have found that the late Mr. Bruce Foote, formerly Superintendent of the Indian Geological Survey, had already come to much the same conclusions as myself with regard to the relationship between early human settlements and certain geological formations.

He says:—

"A consideration of the map of prehistoric localities (published by him in his work on Indian prehistoric and protohistoric Antiquities) . . . . shows that the several peoples concerned were widely distributed over the country, excepting in the mountain and great forest regions of the west of the peninsula, in which, so far as my knowledge goes, no traces have been found of the paleolithic race or races. The localization of all the races has also been influenced in some measure by the distribution of the rocks yielding materials suitable for their respective implements. Thus, there are far more numerous traces of the paleolithic race around the great quartzite yielding groups of hills forming the Cuddapah series of the Indian geologists and the great quartzite shingle conglomerates of the Upper Gondwana system in the Chingleput (Madras), North Arcot and Nellore districts, than in other regions. In diminishing quantities traces of paleolithic man are found to the northward of Kistna valley, where, quartzite becomes a much less common rock. So also to the southward of the Pālār valley, where quartzite becomes a rare material; to the westward on the Deccan plateau, where the stone chippers, finding no quartzite in the Bellary district, had recourse to the banded jasper hæmatite rocks (of the Dharwar system); and further north in the valley of the Kistna, where recourse was had in one instance to hard siliceous limestone.

"The extreme rarity of trap dykes in the south of the peninsula may have been a *vera causa* of the rarity of neolithic remains in the regions south of the Cauvery, while it is certain that in the northern parts of the Deccan plateau, where neolithic remains must abound, dykes of basalt, diorite and diabasic traps are very plentifully distributed. This has reference to their war implements, as their axes are, as a rule, almost without a single exception, made of the trappoid rocks, and specially of the finer grained varieties of these." (*Op. cit.*, 36.)

It is thus evident that the writer of these words was far on the way to enunciating the thesis of this paper. He had recognized that the controlling factor in the distribution of palæolithic and neolithic man in India was the presence or absence of raw materials.

The late Mr. Vincent Ball, also of the Indian Geological Survey, in a paper "On the Mode of Occurrence and Distribution of Gold in India" (*Journal Roy. Geol. Soc. Ireland*, 1880), makes some significant remarks when discussing native gold-washing in India. He states that the native gold washers have tended to concentrate themselves in the richest parts of the gold-producing areas (259–60). "In a part of Western Bengal I found that generations of washers had demarcated limits within which washing was remunerative, and these limits corresponded in a striking degree to the well-defined boundaries between two formations—the metamorphic and the sub-metamorphic. In the area occupied by the former, gold was not absent; but its abundance as contrasted with that in the latter, I ascertained . . . was in the proportion of 1 to 3. Hence, as the washers only managed to eke out a bare subsistence in the sub-metamorphic area, they confined their operations to it" (260). Thus the search for gold has caused a definite concentration of population on a geological formation. This is well shown by comparing the present-day distribution of the Gonds with that of gold. The map shows clearly that the movements of this tribe have been controlled, as Mr. Ball says, by their occupation of gold-washing. Thus in India we see actually at work the process of segregation of population on a geological formation that I have postulated from the distributions of megalithic remains in England. The parallel is the more striking in that the Gonds themselves still erect monuments of the megalithic type. Thus in the Gonds we have an example of a megalith-building people segregating themselves on gold-producing geological formations, and thus providing an exact confirmation of the results of this paper.

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PROCEEDINGS
OF
THE MANCHESTER LITERARY AND PHILOSOPHICAL SOCIETY.

General Meeting, October 5th, 1920.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

Mr. WILLIAM DIXON, *Broadwater, 43, Pine Road, Didsbury, Manchester;* and Mr. GEORGE DAVIDSON ELSDON, F.I.C., Public Analyst, *Municipal Laboratory, 143, Regent Road, Salford;* were elected Ordinary Members of the Society.

Ordinary Meeting, October 5th, 1920.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

A vote of thanks was passed to the donors of the books upon the table. Mr. C. L. BARNES, M.A., drew attention to several works, including :—"*A Monograph of the British Orthoptera,*" by W. J. Lucas (8vo., London, 1920), and "*The British Charophyta,*" Vol. 1, "*Nitelleæ,*" by J. Groves and Bullock Webester (8vo., London, 1920), published by the Ray Society, purchased; "*The Black Smoke Tax*" (8vo., Manchester, 1920), and "*Coal Fires*" (8vo., Manchester, 1920), published and presented by The Manchester Air Pollution Advisory Board; "*Through Lapland with Skis and Reindeer,*" by F. H. Butler (8vo., London, 1919), presented by the Author; "*Festuca rubra near Cardiff,*" by W. O. Howarth (8vo., London, 1919), presented by the Author; "*Report on the Quantum Theory of Spectra,*" by L. Silberstein (8vo., London, 1920), presented by Messrs. Adam Hilger, Ltd.; "*The Royal Exchange,*" by A. E. W. Mason (12mo., London, 1920), presented by The Royal Exchange Assurance Co.; "*To og Tredive Praedikener . . M. Jens Nilssφn . . .,*" by A. Brandrud and O. Kolsrud (4to., Christiania, 1917), presented by The University of Christiania; "*The British Marine Annelids,*" Vol. III, part ii, by W. C. McIntosh (fol., London, 1920), published by The Ray Society, purchased; "*The Chemists' Year-Book*, 1920," Vols. 1 and 2 (16mo., London, &c., 1920), presented by the Editors; and several volumes of poems presented by the Royal Academy of Sciences, Amsterdam.

The PRESIDENT referred sympathetically to the loss the Society had sustained by the death of Sir WILLIAM MATHER, P.C., Mem.Inst.C.E., on September 18th. Sir William Mather had been an Ordinary Member of the Society since 1864; and the Meeting RESOLVED that a message, expressing the Society's sincere sympathy at their loss, be communicated to the relatives of the late member.

The PRESIDENT also announced that:—

(1) Professor C. A. EDWARDS, D.Sc., had been appointed to the Chair of Metallurgy in the University College of Swansea, and would therefore be unable to attend further meetings. The Council had therefore invited Professor T. H. Pear, M.A., B.Sc., to be Acting Honorary Secretary, and in the event of Professor Edwards' resignation, Professor Pear would be nominated by the Council as his successor.

(2) The "Appeal Fund" then stood at a total of £1,337 14s. 6d., and the Council hoped that members who had not already subscribed would see their way shortly to do so.

(3) Certain redecoration in the hall and staircases, and in the lavatories, had been authorised and carried out during the vacation.

Dr. A. E. OXLEY, M.A., read a paper entitled "**Recent Researches in Magnetism.**"

After dealing briefly with the nature of ferro-magnetism, paramagnetism, and diamagnetism, the lecturer went on to consider the characteristic variations of these properties over a range of temperature varying from that of liquid air to 300° C. Practically all substances show a change of magnetic property when crystallisation takes place and in the case of certain diamagnetic substances, definite hysteresis loops, with respect to temperature, have been obtained. These loops are similar to those shown by Nickel-steels which are ferro-magnetic.

These experimental results were interpreted in terms of the electron theory of magnetism, and finally extended, through Tyndall's work on the deportment of crystals in a magnetic field, to interpret the nature of crystal structure and the spacial distribution of electrons within the atom. The atomic configuration so deduced is similar to that of the cubical atom developed by Lewis and Langmuir and is distinct from that of the Bohr theory which fails to account for the magnetic properties. It is considered, however, that these theories may be brought into line, in the near future, by a due recognition of the possible differences between radiating and non-radiating matter.

General Meeting, October 19th, 1920.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

Professor T. H. PEAR, M.A., B.Sc., was elected an Honorary Secretary of the Society in succession to Professor C. A. EDWARDS, D.Sc., resigned.

Mr. HERBERT PHILIP BROWN, M.A., B.Sc., Technical Chemist, Assistant Superintendent, British Dyestuffs Corporation (Blackley) Ltd. (Clayton Branch), *33, Woodlands Street, Cheetham Hill, Manchester;* Mr. ROBERT WILLIAM BLAKELEY, Machinery Buyer, Messrs. Ralli Brothers, and of *4, Seedley Park Road, Manchester;* Mr. W. J. PERRY, B.A., *170, Cecil Street, Moss Side, Manchester;* Dr. ALEXANDER MITCHELL WILLIAMS, M.A., Research Chemist, *c/o The British Cotton Industry Research Association, Shirley Institute, Didsbury, Manchester;* Mr. CHARLES W. DUCKWORTH, F.C.I.S., Chemical Manufacturer, *The Bungalow, Park Road, Monton, Eccles, Manchester;* Mr. FREDERICK DENY FARROW, M.Sc., Research Chemist, *c/o The British Cotton Industry Research Association, Shirley Institute, Didsbury, Manchester;* Mr. PAUL CAPPER, *Redlea, Howard Drive, Hale, Cheshire;* Dr. THOMAS BARRATT, A.R.C.Sc. (Lond.), F.Inst.P., Physicist, *c/o Messrs. Tootal Broadhurst Lee Co. Ltd., 56, Oxford Street, Manchester;* Dr. SYDNEY CROSS HARLAND, Research Botanist, *c/o The British Cotton Industry Research Association, Shirley Institute, Didsbury, Manchester;* Mr. WILLIAM ARTHUR SILVESTER, M.Sc. (Sheffield), Technical Chemist, The British Dyestuffs Corporation Ltd., Blackley, Manchester, and *7, Whiston Road, Crumpsall, Manchester;* Mr. WILLIAM FENTON HIGGINS, Manufacturer, *5, Seymour Road, Cheetham Hill, Manchester;* and Dr. HENRY STEPHEN, O.B.E., Senior Lecturer in Chemistry in the Victoria University of Manchester, *The University, Manchester;* were elected Ordinary Members of the Society.

Ordinary Meeting, October 19th, 1920.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

A vote of thanks was passed to the donors of the books upon the table. These included :—"*The House-Fly . . .*," by E. E. Austin, "*Furniture Beetles . . .*," by C. J. Gahan (Brit. Mus. Economic Sers., Nos. IA and II), (8vo., London, 1920), and "*Summary Guide . . Galleries . . British Museum*" (8vo., London, 1920), presented by The Trustees of the British Museum.

The PRESIDENT referred sympathetically to the loss the Society had sustained by the death of Dr. D. LLOYD ROBERTS, F.R.C.P., F.R.S.E., on September 27th. Dr. Lloyd Roberts was elected an Ordinary Member of the Society in 1880. The Meeting RESOLVED that a message, expressing the Society's sincere sympathy at their loss, be communicated to the relatives of the late member.

Mr. C. E. STROMEYER, O.B.E., Mem.Inst.C.E., read a paper entitled **"An Attempt to Explain the Real Nature of Time, Space and Other Dimensions."**

The author pointed out that in the remote past doubts seem to have been entertained about the reality of time and space, and of matter it seems always to have been believed that it could be made to appear and disappear. Kant and Schopenhauer, who lived in the early part of the last century, were converts to the belief in the indestructibility of matter, but asserted of time and space that they were functions of the brain. They may, therefore, be looked upon as being the innocent originators of the modern idea that the world is mind and matter. In their days energy and its conservation or indestructibility had not been discovered, but they suspected that besides matter there was another reality which they respectively called "das Ding an sich"—the real thing—and "der Wille zum Leben"—the will to live. They did not explain what they meant by reality, and the author pointed out that they should have said that time and space were relatively unreal to matter and to the "real thing," in the same way as length, breadth and depth, are relatively unreal to space, if this be taken as the standard of reality. Mr. Stromeyer then said that dimensions, using the term in its widest sense so as to include time, space, velocity, work, pressure, all the electric, thermometric, and chemical dimensions, were unquestionably factors of energy. Energy always appears as a product of these factors, never as a factor. It stands in marked contrast to every one of its factors in being indivisible quantitatively until it has been divided qualitatively. It also differs from them in that it cannot be located in the sense that length may be said to be located in space, or a Volt in an Ampere. When electric energy has been poured as it were into water, splitting it up into hydrogen and oxygen, that energy is neither in the water, nor in the oxygen, nor in the hydrogen. Thus energy in contrast to its factors or dimensions seems to be the only "real thing"; all its factors, our world, are relatively unreal, but amongst each other they appear relatively real. Thus, contrary to Kant's and Schopenhauer's views, matter is both as real and as unreal as time and space.

Mr. Stromeyer also dealt with the fourth dimension and showed that it was not a real one.

The reading of Dr. W. J. Walker's paper was deferred to the next Ordinary Meeting of the Society.

General Meeting, November 2nd, 1920.

Mr. FRANCIS JONES, M.Sc., F.R.S.E., F.C.S. (*Vice-President*), in the Chair.

Mr. ROBERT GEORGE FARGHER, M.Sc., Head of the Department of Organic Chemistry, *The British Cotton Industry Research Association, Shirley Institute, Didsbury;* Mr. L. J. MORDELL, B.A., Lecturer in Mathematics, *The College of Technology, Manchester;* Mr. JOHN ALFRED CLAYTON, B.Sc. (Vict.), Assistant Master, *Central High School for Boys, Whitworth Street, Manchester;* Professor THEODORE GEORGE BENTLEY OSBORN, D.Sc., Professor of Botany in the University of Adelaide, South Australia, *The University, Manchester;* Dr. DOUGLAS H. CLIBBENS, B.Sc., *c/o The British Cotton Industry Research Association, Shirley Institue, East Didsbury, Manchester;* and Mr. HENRY CARDWELL, M.A., LL.B., Solicitor, *50, Alexandra Road South, Manchester, S.W.;* were elected Ordinary Members of the Society.

Ordinary Meeting, November 2nd, 1920.

Mr. FRANCIS JONES, M.Sc., F.R.S.E., F.C.S. (*Vice-President*), followed by Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

A vote of thanks was passed to the donors of the books upon the table.

Dr. W. J. WALKER, B.Sc., A.Mem.Inst.C.E., read a paper entitled **"The Polytropic Curve and its Relation to Thermodynamic Efficiency (with a Note on the Theory of the Uniflow Steam Engine)."**

This paper is printed in full in the *Memoirs.*

Mr. W. H. PEARSON, M.Sc., A.L.S., read a paper entitled **"Notes on a Collection of Hepatics from the Cameroons, West Coast of Africa."**

This paper is printed in full in the *Memoirs.*

Extraordinary General Meeting, November 16th, 1920.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

Professor F. E. WEISS, D.Sc., F.R.S., F.L.S., was elected an Ordinary Member of Council.

General Meeting, November 16th, 1920.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

Mr. HUMPHREY JOHN DENHAM, M.A. (Oxon.), Research Botanist, *c/o The British Cotton Industry Research Association, Shirley Institute, East Didsbury, Manchester;* Mr. WILLIAM HARRISON, M.Sc. Tech. (Manc.), M.Sc. (Leeds), F.I.C., Research Manager, Messrs. Burgess, Ledward & Co., Limited, *Beechwood, Walkden Road, Worsley, near Manchester;* Mrs. R. H. CLAYTON, *1, Parkfield Road, Didsbury, Manchester;* Dr. CHARLES W. SOUTAR, M.A., Research Chemist, The British Alizarine Co., Ltd., *69, Russell Road, Whalley Range, Manchester;* and Mr. FREDERICK WILLIAM BLACK (Junr.), B.A. (Oxon.), c/o The British Petroleum Company, *9, Trevelyan Street, Eccles, Manchester;* were elected Ordinary Members of the Society.

Ordinary Meeting, November 16th, 1920.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

Mr. WILLIAM THOMSON, F.R.S.E., F.C.S., F.I.C., gave a short demonstration on light produced by rubbing two pieces of fused silica together, and referred to the peculiar smell then emitted.

Mr. A. E. HEATH, M.A., read a paper entitled **"The disinterested character of Science in view of certain of its working maxims."**

The object of this paper was to show that Mach's "principle of economy" and Occam's "principle of parsimony" are not—as would appear on the surface—contradictory. It was contended that the sciences are synthetic; and consist in the setting up of conceptual constructions for the complete description of the fields of primary fact in each science. When alternative conceptual constructions are possible Mach's principle is used to decide between the alternatives. But the constant reference back to the field of primary fact removes from its use any menace to the disinterested character of science. Occam's principle, however, is a maxim only applicable to a process opposite in direction to the synthetic advance of the sciences: namely, the analysis of the field of primary fact itself. It is therefore not contradictory but complementary to the principle of economy.

General Meeting, November 30th, 1920.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

Mr. ROBERT O. BOSWALL, B.Sc. (Lond.), A.M.I.Mech.E., A.F.R.Aë.S., Lecturer in Mechanical Engineering, *The College of Technology, Manchester;* was elected an Ordinary Member of the Society.

At this General Meeting, summoned in accordance with the Articles of Association, the resolution of the Council, and proposed rules, recommending the establishment of a form of "Student Associateship," was adopted by the Society.

STUDENT ASSOCIATES.

Report of Council.

The Council have had under consideration the desirability of admitting to some of the privileges of membership a limited number of persons entering upon scientific careers, who would be unable to pay the present annual subscription. These would usually be post-graduate students, many of whom would doubtless become ordinary members on obtaining salaried positions; some would be research students from abroad working for the Ph.D. degree. The Council therefore invite the approval of the Society to the admission of "student associates," which may conveniently be done under articles 29 and 100 of the constitution, which articles read :—

"29. Persons who are not members of the Society may assist at its ordinary meetings when introduced by members of any class."

"100. The Society may, from time to time, in general meetings, by special resolution, alter and make new provisions and regulations in lieu of, or in addition to, any regulations of the Society from time to time in force."

The following suggested regulations for student associateship embody the details of the scheme now submitted :—

(1) Applicants shall have attained the age of nineteen years, and shall not, except in special circumstances approved by the Council, have exceeded the age of twenty-five years on the date of application.

(2) Applicants shall be engaged in research work or shall, in the opinion of the Council of the Society, be qualified otherwise to take advantage of the privileges offered.

(3) Each applicant shall be nominated by two members of the Society. These members shall be satisfied that the applicant could not afford to join the Society as an ordinary member.

(4) Election shall be by the Council, for one year only, but student associates shall be eligible for re-election under the terms of these regulations. Three-fourths at least of the votes given at an election shall be in favour of the candidate in order to render his election valid.

(5) Student associates shall receive notices of all ordinary meetings and shall have the right to take part in them, as if

they were ordinary members, but shall not have the right to vote at any meeting.

(6) Student associates shall have the right to use the rooms and library, after signing their names, on each occasion, in a book kept for the purpose, but may not take books away from the building.

(7) The feet for student associateship shall be ten shillings and sixpence for the period of one session (April 1st—March 31st).

Ordinary Meeting, November 30th, 1920.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

A vote of thanks was passed to the donors of the books upon the table. These included :—" *Greenwich Catalogue of Stars for* 1910-20," parts 1 and 2, by F. W. Dyson (4to., London, 1920), presented by Greenwich Observatory; and *Bulletins* 68 and 69 of The Bureau of American Ethnology (8vo., Washington, 1919), presented by the Bureau of American Ethnology, Washington.

Professor T. G. B. OSBORN, D.Sc., read a paper entitled

" Notes on Stone Implements from the Cooper's Creek District, South Australia."

The collection exhibited was made in May last during a short visit to Killalpannina, on the Barcoo (Cooper's Creek) in the Lake Eyre Region.

Most of the specimens were found on old camping grounds of the Deari tribe, the survivors of which still live in semi-civilisation in the district centred around Kopperamanna. The damaged knives and the flakes struck off in their manufacture were most abundant in certain places along sandhills, often overlooking a watercourse. From their abundance there it is probable that knives were manufactured in these places, the finished article carried away, and great numbers of flakes and discarded fragments left behind. Upon the camping-grounds scrapers and irregular sharp-edged flakes were more abundant than knife fragments. There is strong reason to believe that, although carefully chipped knives are made, any crude flake struck off at a single blow serves for use as a temporary cutting instrument, provided it has a sharp edge, and that it is discarded after use. A full-blooded member of the tribe, although he wore European clothes and was employed as a camel herd by the Killalpannina station from which he received rations, had in his camp equipment a small bag of stones and a 'hammer.' From one of these he would strike off a flake as needed, for cutting meat or skinning, and throw it away when he had finished with it.

In addition to scrapers, knives, flakes, etc., hammer stones, stones for grinding and for crushing food materials were shown. The grinding stones are held in the hands and worked backwards and forwards upon a larger stone slab in grinding such small seeds as those of *Eucalyptus microtheca* (the dominant tree by water-courses) or *Portulaca* sp. Crushing or pounding stones are used in breaking the hard 'beans' of 'nardoo' (sporocarps of *Marsilea* sp.). These, it is said, are not used as food except in time of scarcity.

Professor A. V. HILL, M.A., Sc.D., F.R.S., read a paper entitled **"The Purpose of Physiology."**

Reared as the handmaid of medicine, physiology has now taken in addition a position for itself as a pure and as an applied science. As the handmaid of medicine, the task of physiology lies in the discovery and statement of the "normal" as distinguished from the "abnormal." As a pure science it is privileged to explore the mechanisms underlying the phenomena of life by any and every means provided by scientific progress. As an applied science, in co-operation with psychology, it deals with such questions as the conditions of maintenance of the "normal," the standards of fitness, mental, moral and physical, which it is possible to attain or desirable to aim at in the various classes of the population, and at the biological factors in the economic or social system. Progress in physiological knowledge may be expected in the regions where physiology verges on the other, and especially on the exact sciences, while the stimulus to the applications of physiology appears on the borders of such subjects as medicine, sport and physical training, industrial fatigue and conditions of work, sociology or economics.

Joint Meeting of the Society with the Manchester Egyptian and Oriential Society, December 9th, 1920.

Mr. R. L. TAYLOR, F.C.S., F.I.C. (*Vice-President*), in the Chair.

Professor T. ERIC PEET, M.A. (President of the Manchester Egyptian and Oriental Society), read a paper entitled **"Ancient Egyptian Mathematics."**

Egyptian mathematics is not a speculative science but purely practical in scope, and is chiefly known to us from the Rhind papyrus in the British Museum, a document written in the reign of a Hyksos King Apepi, but stated by its scribe to be a copy of an older document of the XIIth Dynasty, roughly 1900 B.C.

The notation was cumbrous, there being separate signs only for one and for the various powers of ten, the numbers in between being represented by repetitions of these signs. Thus 37 was written with 3 tens and 7 units.

Fractions were employed, but only those whose numerator was unity. The only exception to this rule was two-thirds, which was regarded as one over one and a half.

Tables for multiplication by 2 existed, and all multiplication by larger numbers had to be achieved indirectly. Thus, to multiply by nine the Egyptian multiplied first by 2, then by 2 again, then by 2 once more thus giving 8 times, and then added on the number itself.

Division by 2 was naturally done by means of the 2-times multiplication table. Division by larger or more complicated numbers was done by trial.

Simple problems, such as the division of a certain number of loaves between a number of persons, gave little trouble, despite the fractions which they sometimes involved.

Many of the problems concerned areas. The area of the rectangle was correctly determined as the product of its two sides, and the circle was said to be the square of eight-ninths of its diameter, a very close approximation to the truth. In the case of the triangle, carelessness of the scribe in the drawing of a figure and our own ignorance of the exact meaning of an Egyptian mathematical term leaves us uncertain whether they had reached the correct solution or not.

Among solid figures the parallelopiped was correctly cubed, and the volume of a cylinder given as the product of the area of its base and its height. The Egyptians showed themselves perfectly clear and competent in dealing with the units of different dimensions. Several problems dealt with a method of determining in a form useful to the stonecutter the batter or slope of a pyramid whose base and height are given, a measurement needed in the dressing of the outer facing-blocks. A problem in the Moscow papyrus sets out to determine the volume of a truncated pyramid, but an ambiguity in one of the measurements prevents us from gauging the nearness of the approximation.

Other practical problems dealt with the exchange of loaves of various sizes against one another or against beer. The basis of calculation was the "cooking strength," or number of loaves or jugs of beer of a fixed size which could be obtained from a bushel of grain.

In conclusion the lecturer dealt with a much misunderstood problem which is one of the rare pieces of evidence for the existence in Egypt of a standard of rings or *shatyw* of various metals.

General Meeting, December 14th, 1920.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

Mr. HAROLD MARTIN SCOTT, Chemist, *32, Queen's Road, West Didsbury, Manchester;* and Mr. A. D. RITCHIE, M.A,. Assistant Lecturer in Chemical Physiology, *The University, Manchester;* were elected Ordinary Members of the Society.

Ordinary Meeting, December 14th, 1920.

THE FIRST JOULE MEMORIAL LECTURE.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

The First Joule Memorial Lecture was delivered by Sir DUGALD CLERK, K.B.E., D.Sc., F.R.S. The subject of the lecture was "**The Work and Discoveries of Joule.**"

This lecture is printed in full in the *Memoirs*.

"Young People's" Meeting, January 5th, 1921.

Mr. FRANCIS JONES, M.Sc., F.R.S.E., F.C.S. (*Vice-President*), in the Chair.

The First "YOUNG PEOPLE'S" Meeting of the Society was held at 3-30 p.m. Short experimental demonstrations were given by Professor W. W. Haldane Gee, on "Flames and Lights," and by Mr. R. W. James on "Liquid Air."

Mr. and Mrs. R. H. Clayton entertained the Guests to tea in the Common Room, at 4.0 p.m.

Professor W. W. HALDANE GEE, B.Sc., M.Sc.Tech., gave a survey of "**Flames and Light.**" from the "flint and steel" to the present day arc lamp. A "flint and steel," tinder-box, early forms of matches, tallow and wax candles, Dalton's magic lanthorn, Bunsen and other burners were exhibited and described. Boyle's introduction of yellow phosphorus in 1680 and the experiment of producing a bright phosphorescent light by dissolving phosphorus in oil of almonds; "musical" and "roaring" flames were also dealt with by the lecturer. Older methods of lighting were contrasted with modern methods, and a demonstration of shadows produced by candles and by an arc lamp was given. In conclusion, a flashlight photograph was taken.

Mr. R. W. JAMES, M.A., described the production of "**Liquid Air**" at a temperature of 200 degrees Centigrade below the temperature of the atmosphere. He gave demonstrations of its properties, and exhibited the rapid freezing of grapes, an india-rubber ball, and beefsteak, which were then smashed with a hammer. Flowers were placed in liquid air and then crumbled to powder; and finally mercury was frozen and made into a wire hook strong enough to support a small weight. The fractionation of liquid air on evaporation was proved by suitable experiments, and the power developed on evaporation was shown by running a small engine charged with liquid air.

General Meeting, January 11th, 1921.

Mr. FRANCIS JONES, M.Sc., F.R.S.E., F.C.S. (*Vice-President*), in the Chair.

Dr. JOHN PRESCOTT, M.A., Lecturer in Mathematics in the College of Technology, Manchester, *14, Granby Road, Cheadle Hulme, Stockport;* and Mr. HAROLD STEVENSON, F.I.C., Assoc. Univ. Coll., Nottingham, Works Chemist, The British Dyestuffs Corporation (Clayton), Ltd., *6, Cranbourne Road, Heaton Moor, Stockport;* were elected Ordinary Members of the Society.

Ordinary Meeting, January 11th, 1921.

Mr. FRANCIS JONES, M.Sc., F.R.S.E., F.C.S. (*Vice-President*), in the Chair.

A vote of thanks was passed to the donors of the books upon the table. These included "*Annals of Botany,*" Vol. 22, presented by Professor F. E. Weiss; six reprints of Mr. David Brownlie's works on Fuel Economy, presented by the Author; and *The Engineer,* now being presented to the Society's library, weekly, by Mr. Harold Moore and Dr. W. R. Ormandy.

Dr. ALFRED A. MUMFORD read a paper entitled "**Testing and Grading of Health and Physical Fitness.**"

The author pointed out the necessity of having fresh physical fitness tests for school children in addition to those at present in use, because school work imposed a strain which increased as the child grew older. This was particularly evident in the indoor school life of the secondary school child. As dealt with in the medical inspection of schools, health had been mainly considered in its relation to exceptional children—the deformed, the diseased, the mentally unfit, &c. It had not been concerned with measuring the fitness of the child to put forth effort. Further tests of capacity to put forth effort were needed. These tests might be based either upon the work of the heart, the work of the lungs, or the work of the nervous system.

Dr. Mumford described the new tests, which are mainly concerned with breathing. He said they had been brought into prominence by the work of the Air Force, and were now being adapted to boys in the Manchester Grammar School and to students in the Manchester University who volunteered for examination.

The first test, dealing with the amount of air used in respiration, was measured by the spirometer; the second, which dealt with the force of the respiration, was measured by pressure against a column of mercury. The third was concerned with the movements of the chest. Dr. Mumford showed the result of these tests at different ages, and exhibited a specially designed waistcoat, by means of which the chest movements could be examined.

General Meeting, January 25th, 1921.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

Miss ANNIE ELLIS, B.Sc., Science Mistress, The Manchester High School for Girls, Dover Street, Manchester, *1, Moon Grove, Rusholme, Manchester;* and Mr. F. J. HARLOW, B.Sc., A.R.C.Sc. (London), Principal of the Blackburn Municipal Technical College, *The Municipal Technical College, Blackburn;* were elected Ordinary Members of the Society.

Ordinary Meeting, January 25th, 1921.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

A vote of thanks was passed to the donors of the books upon the table. These included :—Vols. 1-5 of the "*Journal of the Manchester Astronomical Society*" (8vo., Manchester, 1913-20), presented by the Editor; "*Sir Norman Lockyer, K.C.B., F.R.S.*" by Sir Richard Gregory (12mo., London, 1920), presented by Lady Lockyer; and "*Cheap Steam,*" Vol. IV, 1920 (4to., London, 1921), presented by Messrs. Ed. Bennis & Co., Ltd.

Mr. W. E. ALKINS, M.Sc., read the following papers :—

1. "Variation of *Sphœria*. I. *Sph. lacustre* (Müller), by W. E. ALKINS, M.Sc.;

2. "**Variation of** *Sphæria.* II. *Sph. corneum* (Linné)," by W. E. ALKINS, M.Sc., and MAURICE COOK, M.Sc.; and
3. "**Variation of** *Sphæria.* III. *Sph. pallidum,* Gray," by W. E. ALKINS, M.Sc., and JOHN HARWOOD, M.Sc.

These papers are printed in full in the *Memoirs.*

General Meeting, February 8th, 1921.

Mr. WILLIAM THOMSON, F.R.S.E., F.C.S., F.I.C. (*Vice-President*), in the Chair.

Mr. CHARLES NORMAN WATERS, A.R.C.Sc. (London), Dipl. Imp. Coll. London, Research Chemist, The Chloride Electrical Storage Co., Ltd., Manchester, *29, Carlton Road, Barrfield Road, Irlams-o'th'-Height, Manchester;* and The Reverend ALOYSIUS LAURENCE CORTIE, S.J., F.R.A.S., F.Inst.P., President of the Manchester Astronomical Society, Director of the Stonyhurst College Observatory, *Stonyhurst College, Blackburn;* were elected Ordinary Members of the Society.

Ordinary Meeting, February 8th, 1921.

Mr. WILLIAM THOMSON, F.R.S.E., F.C.S., F.I.C. (*Vice-President*), followed by Sir HENRY MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

A vote of thanks was passed to the donors of the books upon the table. These included :—"*Collected Scientific Papers,*" by John Henry Poynting (8vo., Cambridge, 1920), presented by the Trustees of The Poynting Memorial Fund; and "*Meteorology of the British* (*Terra Nova*) *Antarctic Expedition of 1910-13,*" Vols. I and II (4to., Calcutta, 1919), presented by the Committee for the Publication of the Scientific Results of the Captain Scott Antarctic Fund.

Professor F. E. WEISS, D.Sc., F.R.S., F.L.S., exhibited and commented upon some early specimens of White Butterbur (*Petasites albus*) grown at Disley. Mr. JAMES GRANT, M.Sc.Tech., F.I.C., quoted some local meteorological records of the last month (January).

Mr. CHARLES W. DUCKWORTH, F.C.I.S., read a **"Note on a Unique Set of Hydrometers."**

The hydrometers referred to consist of the usual set of six Twaddell's hydrometers for liquids heavier than water. There is also one for lower specific gravities, viz., .625 to .850.

These hydrometers were made by Mr. John Baptiste Ronchetti, hydrometer and thermometer maker (by appointment) to Her Majesty's Inland Revenue, Clayton, Manchester, about 45 years ago. His workrooms were in a cottage in Ashton New Road, opposite Bank Lane (now Bank Street). The glasses have been in the writer's possession over 40 years, and as they are probably the only ones still in existence he thought it advisable to hand them over to the Society.

Mr. Ronchetti was one of the best hydrometer makers in the trade. He died in 1881, and was interred at St. Joseph's Cemetery, Moston. He was the eldest son of Mr. Charles Joshua Ronchetti—the friend and associate of Dalton and Joule—who made the barometer at present hanging in the Secretary's room, as well as several other instruments for Dalton.

Mr. Charles Joshua Ronchetti was in business in Balloon Street, Manchester, from 1817 to 1821, when he removed to Cateaton Street, until 1828, and was for some time afterwards in St. Ann's Square, as stated on the barometer already referred to.

The late Mr. Joseph Casartelli, who was a member of the Society from January 26th, 1858, until his death in March 1900, at 77 years of age, was a son-in-law of Mr. C. J. Ronchetti. He took over the St. Ann's Square business in 1853 and transferred it to Market Street, where it still remains, and is said to be the oldest established firm in the principal street of the city.

The writer is indebted to Messrs. Joseph Casartelli and Son, of Market Street, for some of the dates relating to the family connection with the maker of the hydrometers, whom he remembers well on account of his somewhat striking personality.

The set of hydrometers was then presented to the Society.

Professor George Unwin, M.A., read a paper entitled **"Samuel Oldknow, the first manufacturer of British Muslins."**

The author exhibited a series of records (1782—1812) which have just been discovered in Oldknow's Mill at Mellor, near Marple. They relate to the business of Samuel Oldknow, one of the first manufacturers of British muslins, a man of some character and enterprise, who towards the close of the eighteenth century was classed with the Arkwrights and the Strutts, of Derby, as a coming "cotton lord." The records disclose in detail the whole process of manufacture, Oldknow's marketing and financial relations, the economy of the handloom weaver's life and conditions in one of the first cotton factories, and Oldknow's connections with Sir Richard Arkwright, Robert Owen, William Radcliffe, and other prominent figures in Lancashire's side of the industrial revolution. The hope was expressed that interest might be awakened in similar records elsewhere.

The muslin manufacture was attempted by Joseph Shaw at Anderton, near Chorley, in 1764, but the first success was achieved by Oldknow, who was born at Anderton in 1756, and returned there about 1780 from Nottingham. In 1784 he carried the manufacture to Stockport, and also carried on a bleaching and dyeing works at Heaton Mersey. Here Oldknow was found from the records to be buying his cotton in Manchester and Liverpool, and giving it out to a score of little spinners round about. From his warehouse 340 weavers of Stockport and the villages within five or six miles received the materials for their handlooms. Robert Owen, then an apprentice at Stamford, had described how Oldknow's British mull muslins at 9s. a yard were bought up by the nobility. Samples sent by him to Lord and Lady Penrhyn had been found, and experts pronounced them to be spun of 70's or 80's counts. In 1788 two London agents took £20,000 worth in four months, and the output for the year may have been £80,000. According to Owen, Oldknow made £17,000 profit in two successive years. He entered into a sort of partnership with Sir Richard Arkwright, who advanced money.

The records of the mill at Mellor, which was built in 1790, were in some respects unique, though not the earliest records of a cotton factory; those of Messrs. Greg at Styal went back further. They showed the weekly wages, the different classes of workers, the operation of the truck system.

In 1798 Oldknow was obliged to put up to auction a good deal of real estate and all his industrial investments but the Mellor factory, which he kept until his death in 1828. His Stockport mill became the scene of William Radcliffe's experiments with the dressing machine which led to the perfecting of the power-loom.

Joint Meeting of the Society with the Faraday Society, February 11th, 1921.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), introduced Professor A. W. PORTER, D.Sc., F.R.S. (*President of the Faraday Society*), who then took the Chair.

Dr. ALLAN FERGUSON, M.A., read a paper entitled "STUDIES IN CAPILLARITY." "**Part I. Some General Considerations, and a Discussion of the Methods of Measuring Interfacial Tensions.**"

"**Part II. A Modification of the Capillary Tube Method for the Measurement of Surface Tensions.**" By Dr. ALLAN FERGUSON, M.A., and Mr. P. E. DOWSON, M.A., was also read by Dr. Ferguson.

A number of manometers were exhibited, including a Chattock tilting manometer, and a Threlfall micromanometer lent for the occasion by the Cambridge and Paul Scientific Instrument Company.

These papers are printed in full in the *Memoirs.*

General Meeting, February 22nd, 1921.

Mr. FRANCIS JONES, M.Sc., F.R.S.E., F.C.S. (*Vice-President*), in the Chair.

Mr. JAMES BARR, B.Sc. (London), A.I.C., Technical Chemist, The North British Chemical Co., Ltd., Manchester, and *Hillside, Townsliffe Lane, Marple Bridge, Derbyshire;* was elected as an Ordinary Member of the Society.

Ordinary Meeting, February 22nd, 1921.

Mr. FRANCIS JONES, M.Sc., F.R.S.E., F.C.S. (*Vice-President*), in the Chair.

Mr. J. WILFRID JACKSON, F.G.S., and Mr. R. G. FARGHER, M.Sc., were nominated auditors of the Society's accounts for the session 1920—1921.

A vote of thanks was passed to the donors of the books upon the table. These included :—Vol. xxvi. of the *"Annals of Botany"* (8vo., London, 1912), presented by Professor F. E. Weiss.

Mr. W. H. CORKILL read a paper entitled **"Manx Mines and Megaliths."**

This paper is printed in full in the *Memoirs.*

Mr. W. J. PERRY, B.A., read a paper entitled **"The Problem of Megalithic Monuments and their Distribution in Great Britain."**

It is possible to associate the dolmens and stone circles which are scattered about in various parts of the country with certain geological formations: in Devon and Cornwall, with the granite; in Dorset and Wilts., with the Upper Chalk; in Oxford, with the Lias; in Derbyshire, with the carboniferous limestone; and in Wales, with the metalliferous rocks, including the carboniferous limestone. This would suggest that the builders of megaliths went to Devon and Cornwall for gold, tin, or both, to Dorset and Wilts. for flint, to Derbyshire for lead, and to Wales for lead, copper, gold, and so on. In the North Riding of Yorkshire the Romans, when they went to Whitby to get jet, found stone circles in the neighbourhood; in Derbyshire they found stone circles round the lead mines; in Shropshire they found stone circles near the lead mines of the Minsterley district; and in parts of Wales their mining centres possessed megalithic monuments. So apparently, the megalith builders were attracted to these places by the same thing as the Romans, the desire for certain forms of wealth.

The principal of association of human settlement and geological formations provides us with an instrument of research in human geography. Such a distribution as that of the megalith builders suggests the existence of purely economic motives in their settlement of the country. In the case of the Romans, the fact that their settlements are not wholly in direct association with geological formations shows that political aims also played their part in influencing their choice of localities for settlement. Communities such as those of the Saxons and Teutonic tribes apparently show no relationship whatever to geological formations, and in these cases it is obvious that entirely different motives from those which actuated the megalith-builders were at work. It would seem, from the analysis of the localisation of the settlements of any given civilisation, that it would be possible to estimate the parts played by the purely economic and by the purely political forces in the life of the community, and, by the comparative study of various civilisations, to help towards the building-up of a stable theory of society.

General Meeting, March 8th, 1921.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

Mr. R. F. CLARK, Resident Engineer, The Cambridge and Paul Scientific Instrument Co., Ltd., *8, Exchange Street, Manchester;* was elected an Ordinary Member of the Society.

Ordinary Meeting, March 8th, 1921.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

A vote of thanks was passed to the donors of the books upon the table. These included:—Vols. xxiii. and xxiv. of the *"Annals of Botany"* (8vo., London, 1909 and 1910), presented by Professor F. E. Weiss; and *"Average Figures for the Performance of Some Different Types of Steam Boilers,"* by David Brownlie (8vo., London, 1920), presented by the Author. Mr.

G. K. Davis is presenting *The Chemical Trade Journal and Chemical Engineer* to the Society's library.

The Journal of the Royal United Service Institution and *The Aëronautical Journal* are no longer received for the library.

Professor MILES WALKER, M.A., D.Sc., M.Inst.E.E., read a paper entitled **"Some Chapters from the History of English Spelling and the Need of a New Chapter."**

This paper is printed in full in the *Memoirs*.

Ordinary Meeting, March 22nd, 1921.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

A vote of thanks was passed to the donors of the books upon the table. These included :—*Kolloid Zeitschrift*, vols. 26, 27 (1—4 and 6) and 28 (1), and *Kolloidchemische Beihefte*, vols. 12 and 13 (1-2), presented by Mr. L. A. Fenn.

Dr. W. M. TATTERSALL exhibited live specimens of Land Leeches found at Platt Fields, Fallowfield. Similar leeches have only once previously been reported in this neighbourhood.

Mr. CHARLES W. DUCKWORTH, F.C.I.S., read the following note :—

Enclosed with an Indian letter which I received on February 23rd, 1921, are particulars of a meeting in Calcutta convened for presentation of an address to Sir J. C. Bose, F.R.S., after his return from Europe. In the course of his reply, Sir J. C. Bose said : "Perhaps the most momentous incident of my visit was that they all told me that my work had found acceptance in England, Scandinavia and France, but had I the courage to face the German physiologists, some of whose conclusions my work had upset. My stay in Europe was drawing to a close, and I had less than a week to spare. I therefore went to Berlin without notice, and drove directly to the celebrated Physiological Institute at Dalheim, presided over by the eminent and veteran physiologist Haberlandt. I was received with marked coolness and suspicion as having come from the Allied Countries; the anti-foreign feeling was then at its highest. I only asked for fair play. Let all the leading scientists be invited, and I would be ready to meet the shock of hostile criticisms. A lecture was organized and a miracle happened, for in less than 15 minutes the whole audience gave expression of their warmest appreciation. So complete was the conversion from scepticism that in his subsequent address Professor Haberlandt declared that it was no mere accident that it should have been an Indian investigator who had in so high a degree perfected the new method of inquiry."

Mr. L. A. BORRADAILE, M.A., read a paper entitled "**The Coral-gall Prawn** *Paratypton*."

This paper is printed in full in the *Memoirs*.

General Meeting, April 12th, 1921.

Mr. WILLIAM THOMSON, F.R.S.E., F.C.S., F.I.C. (*Vice-President*), in the Chair.

At this General Meeting, summoned in accordance with the Articles of Association, the following resolution of the Council was submitted to the Society:—

"That the Council be constituted as follows: a President, four Vice-Presidents, two Secretaries, a Treasurer, two Librarians, a Curator and nine other ordinary members."

This resolution was adopted.

Dr. ARNOLD SCHEDLER, *c/o The Clayton Aniline Co., Ltd., Clayton, Manchester;* was elected an Ordinary Member of the Society.

Ordinary Meeting, April 12th, 1921.

Mr. WILLIAM THOMSON, F.R.S.E., F.C.S., F.I.C. (*Vice-President*), in the Chair.

A vote of thanks was passed to the donors of the books upon the table. Recent accessions included:—"*The British Fresh Water Rhizopoda and Heliozoa*," vol. v., by G. H. Wailes (8vo., London, 1921), published by the Ray Society, purchased.

Mr. H. E. WILLIAMS, F.C.S., read a paper entitled "**The Theory of Cellulose Solvents.**"

This paper is printed in full in the *Memoirs*.

Annual General Meeting, April 26th, 1921.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S. (*President*), in the Chair.

The Annual Report of the Council and the Statement of Accounts were presented, and it was resolved:—"That the Annual Report, together with the Statement of Accounts, be adopted, and that they be printed in the Society's *Proceedings*."

A vote of thanks to the retiring officers and other members of Council was passed unanimously.

The following members were elected officers of the Society and members of the Council for the ensuing year :—

President : T. A. COWARD, F.Z.S., F.E.S.

Vice-Presidents : R. L. TAYLOR, F.C.S., F.I.C.; WILLIAM THOMSON, F.R.S.E., F.C.S., F.I.C.; Sir HENRY A. MIERS, M.A., D.Sc., F.R.S.; W. HENRY TODD.

Secretaries : H. F. COWARD, D.Sc., F.I.C.; T. H. PEAR, M.A., B.Sc.

Treasurer : R. H. CLAYTON, B.Sc.

Librarians : C. L. BARNES, M.A.; WILFRID ROBINSON, D.Sc.

Curator : W. W. HALDANE GEE, B.Sc., M.Sc.Tech., A.M.I.E.E.

Other members of the Council : ARTHUR LAPWORTH, D.Sc., F.R.S., F.I.C.; C. E. STROMEYER, O.B.E., Mem.Inst.C.E., Mem.Inst.M.E.; W. M. TATTERSALL, D.Sc.; LEONARD E. VLIES, F.C.S., F.I.C.; F. W. ATACK, M.Sc.Tech., B.Sc., F.I.C.; F. E. WEISS, D.Sc., F.R.S., F.L.S.; FRANCIS JONES, M.Sc., F.R.S.E., F.C.S.; LAURA START, M.Ed.; SYDNEY CHAPMAN, M.A., D.Sc., F.R.S.

Ordinary Meeting, April 26th, 1921.

Sir HENRY A. MIERS, M.A., D.Sc., F.R.S., in the Chair.

Mr. C. L. BARNES, M.A., made a short communication on the Green Ray sometimes seen when the sun is setting behind a well-defined horizon, the last appearance of the disc being a bright green flash. He referred to the novel of that name written many years ago by Jules Verne, and to an explanation of the occurrence in *Nature* of February 10th, 1921.

Mr. A. D. RITCHIE, M.A., read a paper entitled **"The Nature of the External World."** An examination of Professor A. N. Whitehead's views on the Scope of Physics.

Most of the knowledge we possess can be included under the title of Physics, as every worker in every branch of science applies its results and methods. Physics is an experimental science that depends upon experience. It is strange therefore that the entities and processes in terms of which physics describes the external world are none of them such as we are acquainted with by experience. Some thinkers have argued that the conceptions of physics are not real but merely convenient fictions. Professor Whitehead, on the other hand, endeavours to demonstrate that these conceptions are perfectly logical constructions from the primitive data of experience and hence are real ingredients of nature.

The fundamental facts from which he starts are Events.

These are constituents of our immediate awareness, and from the nature and relations of events he builds up a consistent theory of Space and Time, and defines Rest and Motion and the metrical properties that are required for experimental procedure.

Extraordinary General Meeting, May 10th, 1921.

Mr. W. HENRY TODD (*Vice-President*), in the Chair.

At this Extraordinary General Meeting, summoned in accordance with the Articles of Association, the following resolution, submitted by the Council in response to a requisition signed by five ordinary members of the Society, was submitted to the Society :—

"That this meeting of the Manchester Literary and Philosophical Society, being convinced that the spelling of many of our English words is unjustifiable either from the etymological or from the utilitarian point of view, and that much of the time of our school children is at present wasted on a useless and illogical system, calls upon His Majesty's Ministers to refer to an Academy the power of simplifying our spelling and making it more in accordance with the true spirit of English orthography."

This resolution was adopted.

General Meeting, May 10th, 1921.

Mr. W. HENRY TODD (*Vice-President*), in the Chair.

Mr. PERCY ENFIELD DOWSON, M.A., Research Chemist, *The Chemical Department, Messrs. Rowntree and Co., Ltd., York;* was elected an Ordinary Member of the Society.

Ordinary Meeting, May 10th, 1921.

Mr. W. HENRY TODD (*Vice-President*), in the Chair.

A vote of thanks was passed to the donors of the books upon the table. These included :—"*The Vegetation of the Siberian-Mongolian Frontiers,*" by H. Printz (fol., Trondhjem, 1921), presented by the Kongeligt Norsk Videnskabers Selskab.

Professor W. W. HALDANE GEE, B.Sc., M.Sc.Tech., said that the history of the *Manchester Guardian,* by Mr. W. Haslam Mills, published in the recent centenary number, was of interest in connection with the past membership of the Society. John Taylor, the father of John Edward—the founder and first editor of the newspaper—became a member in 1808. At the age of

15 he had lessons from John Dalton. Professor Gee exhibited a ledger showing Dalton's method of recording the attendance of his pupils, with his fees based on a cost of 2s. 6d. per lesson. John Edward became a member in 1828, and his son, also a John Edward, who edited the *Guardian* from 1861 to 1871, was elected in 1856. Five of the early reformers connected with the "Manchester Constitutional Society," whose names are given by Mr. Mills, were members of the Literary and Philosophical Society. J. C. Dyer, a Vice-President of this Society, was one of the promoters of the *Guardian*. His remarkable history is given by Angus Smith in the centenary volume.

Mr. C. L. BARNES, M.A., quoted from a letter in *Nature* of April 28th, referring to the effect of a high-speed propeller in attracting gnats, though at first there were none to be seen. They were killed in large numbers by the blades, which were afterwards found to be stained with their blood. A similar observation was recorded by the late Sir Hiram Maxim, who observed that the drone of a dynamo drew mosquitoes to the instrument. Allusion was also made to Isaiah, vii, 18, where the words "the Lord shall hiss for the fly . . . . and for the bee," seem to point to an early knowledge of the phenomenon.

Mr. C. E. STROMEYER, O.B.E., Mem.Inst.C.E., read a paper entitled **"The Lorentz-Einstein Relativity."**

Leaning on his previous paper the author admitted the possibility of time and space having secondary characteristics as claimed by relativitists. But he disputed their claim to be able to evolve these secondary characteristics by Euclidean methods out of Euclidean space and time. He subjected Einstein's rendering of Lorentz's mathematics to a searching analysis and pointed out that the results were obtained by the fairly frequent introduction of the expression nought divided by nought which is the mathematical way of writing this is an unknown quantity. Starting from any suitable imaginary proposition, for instance that no velocity can exceed that of light, the author showed in a few lines how to evolve the desired relatively correction formulæ, but pointed out that they have no more reality than the imaginary proposition. In conclusion he suggested that all our difficulties would vanish if we would admit that, whether there be an ether or not, whether it be solid or gaseous, each atomic source of light or heat, light and heat being electric phenomena, surrounds itself many billion times per second with electric fields which partake of its movements, in the same way as the infinitely great magnetic fields which surround a wire carrying an electric current partake of the movements of that wire.

PROCEEDINGS

OF

THE MANCHESTER LITERARY AND PHILOSOPHICAL SOCIETY.

CHEMICAL SECTION.

Ordinary Meeting, October 29th, 1920.

Mr. J. H. LESTER, M.Sc., F.I.C. (*Chairman*), in the Chair.

The CHAIRMAN introduced a discussion on **"The Textile Chemist."**

Distinction was made between Textile Chemistry and the sciences in which the Textile Chemist should be trained. Physics is at least as important as Chemistry to the chemist in textile work for he is expected to have a grasp of all matters which are merely "Science" to the works manager and to men not accustomed to distinguishing between Chemistry and Physics. The chemist in a dye-making works is only a Textile Chemist when he deals with the textile process of dyeing.

The textile chemist who aims at occupying a leading position in the industry, and not to be merely a works tester or analyst, should have a more thorough training in pure chemistry and physics than is possible in a three years' graduate course in textile technology. The technology of his course should be taken mainly in the post-graduate stage in a technical college as distinct from a technical school. The school and college are of equal importance, but the former should be for the training of analysts and works foremen and the latter for a more advanced type of scientific technologist.

Ordinary Meeting, November 29th, 1920.

Mr. J. H. LESTER, M.Sc., F.I.C. (*Chairman*), in the Chair.

Mr. HAROLD E. POTTS, M.Sc., introduced a discussion on **"How can the results of chemical research be best protected by patents?"**

The paper outlined the collaboration necessary between a research director and a patent agent if the results of research are to be successfully protected by patents. Examples were given showing that when a new process is developed, three lines of research are required: first, further development of the original idea; second, obtaining practical data required by the process manager; and third, information required if a watertight patent is to be obtained. The lecturer then discussed the differences between the technical and legal attitude of mind with a view to harmonising the conflicting claims of these various problems. It was shown that the technical mind, in a typical case, is creative and subjective, and that the legal mind is analytic and objective. These latter qualities are essential to generalise the invention for the purpose of legal protection. It was argued that analysis and objectivity, far from hindering research, are actually in the true spirit of scientific method. It was concluded that if the patent agent studied the subject so that he could freely and intelligently criticise the research programme, the requirements of the law could be met, and at the same time the research itself would be assisted because of the emergence of fundamental principles.

Ordinary Meeting, December 17th, 1920.

Mr. J. H. LESTER, M.Sc., F.I.C. (*Chairman*), in the Chair.

Mr. DAVID BROWNLIE, B.Sc., F.C.S., A.I.Mech.E., introduced a discussion on "**Suggestions for a National Scheme of Fuel Economy.**"

The opener dealt in detail with the different practical methods that are possible for carrying out a National Scheme of Fuel Economy and the gist of the paper was, that for an expenditure of about £200,000,000 it would be possible to reduce the coal bill of Great Britain by at least 50,000,000 tons of coal per annum, valued at £100,000,000.

The lecturer dealt with a mass of figures which were, however, shown on twenty or thirty lantern slides so as to enable the audience to follow the argument.

He suggested that the first thing was to develop the water power resources of Great Britain, which would save about 8,000,000 tons of coal per annum now used for power production. Secondly, to develop to a proper extent the utilisation of blast furnace gas, which would save at least another 5,000,000 tons per annum.

Mr. Brownlie then dealt in detail with the necessity of bringing up-to-date the steam generation plants of Great Britain, and he gave a mass of statistics relating to the performance of three or four hundred boiler-plants which he had personally investigated and which showed that the net working efficiency of the boiler-plants of Great Britain is only about 60% and could easily be made 75%, thus showing the possibility of saving 20% of the coal used for steam generation and saving about 15,000,000 tons per annum. The lecturer also dealt in detail with the proper utilisation of refuse coal at collieries and the development of "pass-out steam" in industries using mixed high pressure and low pressure steam. Also, of the avoidance of condensation losses in steam-pipe circuits and friction losses in connection with bad drives. He was of the opinion (and dealt with these matters) that there was little to be expected in the immediate future for the development of peat, the use of oil fuel, and the Super-power station scheme.

The question of a National Scheme of Fuel Economy is a very intricate and difficult one and is a combination of a number of different methods of working to one end.

Ordinary Meeting, January 28th, 1921.

Mr. J. H. LESTER, M.Sc., F.I.C. (*Chairman*), in the Chair.

Dr. W. R. ORMANDY, F.I.C., introduced a discussion on

"Volatile Fuels with special reference to Alcohol."

Dr. Ormandy dealt in the first place with the position of the petrol supplies since the war and up to the recent trade depression. He provided statistics as to the world production of motor vehicles, and urged that if trade conditions became normal the demand for petrol would undoubtedly exceed the supply in the near future. He pointed out, in reference to motor benzol, that this at present was a by-product, chiefly from coke ovens producing blast furnace coke, and that the quantity was regulated by the state of the steel trade. He spoke hopefully about the slow development of low temperature distillation, but pointed out that up to the present he did not know of any commercially successful low temperature distillation process. He referred briefly to the possibility of new applications of steam, to suction gas producers, and to engines of the Diesel type. In his opinion it appears that alcohol is the only alternative fuel, and he brought forward much evidence to show that it was an eminently suitable fuel, either in admixture with benzol, petrol or ether, made from the alcohol itself. The production of alcohol was dealt with, and the difficulties of denaturing and distribution were shortly touched upon. The question as to whether alcohol could be produced in this country was briefly discussed, and the conclusion arrived at that mass production would have to take place in tropical and sub-tropical dependencies if production were to be kept within the Empire.

Ordinary Meeting, February 25th, 1921.

Professor A. G. GREEN, M.Sc., F.R.S., F.I.C., in the Chair.

Mr. F. W. ATACK, M.Sc.Tech., B.Sc., F.I.C., introduced a discussion on **"Some Views on Nitrogen Valency."**

Ordinary Meeting, March 18th, 1921.

Mr. J. H. LESTER, M.Sc., F.I.C. (*Chairman*), in the Chair.

Mr. JOHN ALLAN, F.C.S., introduced a discussion on **"Collegiate Training and the Chemical Engineer."**

Ordinary Meeting, April 29th, 1921.

Mr. J. H. LESTER, M.Sc., F.I.C. (*Chairman*), in the Chair.

Professor H. B. DIXON, C.B.E., M.A., Ph.D., F.R.S., introduced a discussion on **"Researches on Alcohol as a Motor Fuel."**

Annual General Meeting, May 6th, 1921.

Mr. J. H. LESTER, M.Sc., F.I.C. (*Chairman*), in the Chair.

The following members were elected Officers of the Section and members of the Committee for the ensuing year :—

Chairman : LEONARD E. VLIES, F.C.S., F.I.C.

Vice-Chairman : J. H. LESTER, M.Sc., F.I.C.

Hon. Secretary : DAVID CARDWELL, M.Sc., F.I.C.

Other members of the Committee : EDWARD ARDERN, D.Sc., F.I.C.; F. W. ATACK, B.Sc., M.Sc.Tech., F.I.C.; W. H. BENTLEY, D.Sc., F.C.S.; R. H. CLAYTON, B.Sc.; HAROLD MOORE, M.Sc.Tech., F.C.S., A.I.C.; J. E. MYERS, O.B.E., D.Sc.; D. M. PAUL, B.Sc., A.I.C.; RONA ROBINSON, M.Sc., A.I.C.; and T. ROLAND WOLLASTON, M.Inst.Mech.E.

Ordinary Meeting, May 6th, 1921.

The ordinary meeting arranged for this date was postponed.

MANCHESTER
LITERARY AND PHILOSOPHICAL SOCIETY.

Annual Report of the Council, April, 1921.

Membership.

At the beginning of the Session the Society had an ordinary membership of 326. Since then 54 new members have joined the Society. Thirty-three members have resigned, one has been elected a corresponding member, and three members (Mr. T. G. MARSH, Sir WILLIAM MATHER, P.C., Mem.Inst.C.E., and Dr. D. LLOYD ROBERTS, F.R.C.P., F.R.S.E.) have died. There are, accordingly, at the end of the session, 343 ordinary members of the Society. The Society has also lost by death one corresponding member (Mr. C. W. SUTTON, M.A.) and four honorary members (Sir WILLIAM DE W. ABNEY, K.C.B., D.C.L., D.Sc., F.R.S., Professor R. B. CLIFTON, M.A., F.R.S., Sir J. NORMAN LOCKYER, K.C.B., LL.D., Sc.D., F.R.S., and Professor WILHELM PFEFFER, For.Mem.R.S.).

On the nomination of the Council, Mr. R. F. GWYTHER, M.A., has been elected a corresponding member of the Society.

Student Associates.

The Society has decided to admit as "Student Associates," at a subscription of 10s. 6d. each, a limited number of persons entering upon scientific careers who are anxious to make use of the advantages of the Society but who could not afford to join as ordinary members. This scheme will come into operation at the beginning of the Session 1921-22.

Meetings, 1920-21.

Twenty-five papers have been read at the Society's meetings during the year; seven shorter communications have also been made. In addition, eight meetings have been held by the Chemical Section.

Several novel features have been introduced during the year. A "Young People's Meeting" was held in January, at which experimental demonstrations by Professor W. W. Haldane Gee and by Mr. R. W. James were given, and Mr. and Mrs. R. H. Clayton entertained the guests to tea in the Common Room.

The large attendance and the enthusiasm shown by the guests, lead the Council to hope that they may be able to hold similar meetings annually.

Two Joint Meetings were also held successfully: the first, with the Manchester Egyptian and Oriental Society, at which Professor T. Eric Peet gave an address on *"Ancient Egyptian Mathematics"*; the other, with the Faraday Society, at which Dr. Allan Ferguson and Mr. P. E. Dowson read papers entitled *"Studies in Capillarity,"* Parts I and II, which were followed by a lengthy discussion by a large audience.

The First Joule Memorial Lecture was held on December 14th, 1920, when Sir DUGALD CLERK, K.B.E., D.Sc., LL.D., F.R.S., gave an address on *"The Work and Discoveries of Joule."* The address will be published in the Society's *Memoirs.* A dinner in honour of the lecturer was held the same evening.

Society's Accounts.

The cash account of the Society and a statement of assets and liabilities are appended to this report.

The statement of assets and liabilities shows a considerable increase in the Society's assets, including the new premises.

Society's Library.

The Librarian reports that during the Session 580 volumes have been stamped, catalogued and pressmarked; 423 of these were serials. These figures include 136 of the separate works from the library of the old Manchester Chemical Club. The total number of volumes catalogued to date is 39,140.

The additions to the library for the Session amounted to 910 volumes: 717 serials, and 193 separate works. The donations (exclusive of the usual exchanges) were 54 volumes; 3 volumes were purchased in addition to those regularly subscribed for. During the year 87 volumes have been bound in 72 covers. In the previous Session the corresponding numbers were 150 volumes in 102 covers.

The Society now subscribes to *The Chemical Age* and *The Gas Journal.* The donations to the Society's Library during the session include gifts of books by Mr. F. W. Atack, Messrs. Edward Bennis & Co., Ltd., Mr. David Brownlie, Mr. F. H. Butler, Mr. L. A. Fenn, Messrs. Adam Hilger, Ltd., Mr. W. O. Howarth, Lady Lockyer, Professor F. E. Weiss, the Trustees of the Poynting Memorial Fund; the Committee for the Publication of the Scientific Results of the Captain Scott Antarctic Fund; the Trustees of the British Museum (Natural History); the Patent Office Library, London; the Director of the Royal

Observatory, Greenwich; the Meteorological Office, London; the Manchester Astronomical Society; the Director of the Geological Survey of India; the Académie Royale, Brussels; the Bataviaasch Genootschap van Kunsten en Wetenschappen, Batavia; the Yale University Press, New Haven, Conn., U.S.A.; the University of Washington Library, Seattle; the Bureau of American Ethnology, and the Smithsonian Institution, Washington; and the Department of Commerce, United States Coast and Geodetic Survey.

The Meteorological Magazine is presented by the Meteorological Office, London. The Indian Institute of Science (*Journal*), Bangalore, has been placed on the Society's list of exchanges. *The Chemical Trade Journal* is being presented by Mr. G. K. Davis; *The Engineer,* by Messrs. Ormandy and Moore; and *The Textile Recorder,* by Mr. Frank Nasmith. *The Contract Journal* is not now subscribed for; and *The Aëronautical Journal* and *The Journal of the Royal United Service Institution* are no longer received.

The library continues to be satisfactorily used for reference purposes. 357 volumes have been borrowed from the library during the past year. The number of books borrowed during the previous year was 434, and during 1918-19, 283.

Certain duplicate sets of periodicals have been disposed of during the year.

The Society has not yet obtained certain journals, of German and Austrian origin, the delivery of which was interrupted by the War. It is hoped to purchase the back numbers of these journals as the Society's funds permit, priority being given to journals most needed by members.

The publication of the Society's *Memoirs and Proceedings* has been continued under the supervision of a new and active Editorial Committee. During the year volume 63 (1918-19), and volume 64 (1919-20), part I, of the *Memoirs and Proceedings* have been published. The remainder of volume 64 (complete in part II) and volume 65 (1920-21), part I, are in the printer's hands. A List of Instructions to Authors has also been prepared.

Donations.

The Society has received from Mr. C. W. Duckworth a unique set of hydrometers, made by Mr. John Baptiste Ronchetti about 45 years ago (the set consists of six Twaddell's hydrometers for liquids heavier than water, with one for lower specific gravities, *i.e.*, .625 to .850); and from Engineer Commander E. C. Smith a photographic reproduction of the Society's engraving of Peter Ewart.

Chemical Section.

Rules for the Chemical Section were adopted early in the session. The following Officers were elected :—Chairman, Mr. J. H. Lester; Vice-Chairman, Mr. R. H. Clayton; Secretary, Mr. David Cardwell. 153 members have joined the Section. Their meetings follow the procedure of the old Chemical Club, that is, a subject is introduced by a short address which is followed by a general discussion. Since the object of the meeting is to encourage the free interchange of knowledge and the expression of opinions and ideas which are often not sufficiently mature for publication, the addresses will not, as a rule, be submitted for publication. The following were the subjects of debate at meetings held during the session :— "*Alchemy and chemistry among the Chinese,*" "*The relation between chemical constitution and physiological action,*" "*The Textile Chemist,*" "*How can the results of chemical research be best protected by patents?*", "*Suggestions for a national scheme of fuel economy,*" "*Volatile fuels, with special reference to alcohol,*" "*Some views on nitrogen valency,*" and "*Collegiate training and the chemical engineer.*"

Other Societies.

In pursuance of the policy discussed and approved by the Society during recent years, arrangements have been made whereby the following Societies were enabled to hold their meetings regularly in our rooms :—The Manchester Astronomical Society, The Manchester Microscopical Society, The Manchester Statistical Society, and the Society of Dyers and Colourists (Manchester Section). Occasional meetings of other Societies have also been held, namely, The Institute of Chemistry (Manchester Section), The Lancashire and Cheshire Antiquarian Society and the Manchester and Salford Sanitary Association.

Society's House.

During the summer the entrance hall, staircases and lavatories were redecorated, and the glazed tiles in the areas washed and the ironwork repainted. A new mahogany door, part of the building extension and alteration scheme, has been made to open from the landing into the Common Room.

The house is now open from 9.0 a.m. to 10.0 p.m. every weekday except Saturday, on which day the hours are 9.0 a.m. to 6.0 p.m.

Building Extension and Alterations.

A sum of £1,369. 17s. 11d. has been received from or promised by 111 members towards the sum required to carry out the proposed scheme of building extension and alterations.

The plot of land requisite for the extension of the premises has been purchased at a cost of £1,069. 7s. 1d., from which rents will be received until such time as funds permit of the carrying out of the building extension.

COMMITTEES.

The Committees appointed by the Council during the year were as follows :—

House and Finance.

The PRESIDENT, Mr. C. L. BARNES, Mr. FRANCIS JONES, Mr. R. L. TAYLOR, Mr. W. H. TODD, Mr. KENNETH LEE, Mr. L. E. VLIES, Dr. H. F. COWARD and Professor T. H. PEAR.

Wilde Endowment.

The PRESIDENT, Mr. FRANCIS JONES, Mr. W. H. TODD, Dr. H. F. COWARD and Professor T. H. PEAR.

Special Library and Apparatus.

The PRESIDENT, Mr. FRANCIS JONES, Mr. R. L. TAYLOR, Mr. C. L. BARNES, Professor W. W. HALDANE GEE, Mr. DAVID CARDWELL, Mr. FRANCIS NICHOLSON, Professor F. E. WEISS, Dr. H. F. COWARD, Professor T. H. PEAR and the ASSISTANT SECRETARY.

New Premises Committee.

Mr. R. H. CLAYTON, Mr. C. L. BARNES, Mr. L. E. VLIES, Dr. H. F. COWARD and Professor T. H. PEAR.

Publications Committee.

Professor F. E. WEISS (Chairman), Mr. F. W. ATACK, Professor SYDNEY CHAPMAN, Professor W. W. HALDANE GEE, Professor T. H. PEAR and the ASSISTANT SECRETARY.

NOTE.—The Treasurer's Accounts of the Session 1920-1921 have been endorsed as follows:

April 5th, 1921. Audited and found correct.

We have also seen, at this date, the Certificates of the following Stocks held in the name of the Society :—£1,225 Great Western Railway Company 5% Consolidated Preference Stock, Nos. 12,293, 12,294, and 12,323; £7,500 Gas Light and Coke Company Ordinary Stock (No. 8/1960); £100 East India Railway Company 4% Annuity Stock (No. 4032); and the deeds of the Natural History Fund, of the Wilde Endowment Fund, those conveying the land on which the Society's premises stand, and the Declarations of Trust.

Leases and Conveyances dated as follows :—

22nd Sept., 1797.
23rd Sept., 1797.
25th Dec., 1799.
25th Dec., 1799.
23rd Dec., 1820.
23rd Dec., 1820.

Declarations of Trust :—

24th June, 1801.
23rd Dec., 1820.
8th Jan., 1878.

Appointment of New Trustees :—

30th April, 1851.

We have also seen at this date Conveyance dated 7th December 1920, relating to the recently acquired property 21, Back George Street, Manchester.

We have also seen Bankers' acknowledgment of the investment of £300 in the 5% War Loan :—2 Bonds for £100 each, Nos. 71827 and 366270; and 2 Bonds for £50, Nos. 131577 and 31358.

We have also verified the balances of the various accounts with the bankers' pass books

(*Signed*) J. WILFRID JACKSON.
R. G. FARGHER.

MANCHESTER LITERARY

Dr. *W. Henry Todd, Treasurer, in Account with the*

	£	s.	d.	£	s.	d.
To Balance, 1st April, 1920				64	19	6
To Members' Subscriptions :—						
Half Subscriptions, 1908-09, 1 at £1 1s. 0d.	1	1	0			
„ 1909-10, 1 „ „	1	1	0			
„ 1910-11, 1 „ „	1	1	0			
„ 1911-12, 1 „ „	1	1	0			
„ 1912-13, 1 „ „	1	1	0			
„ 1918-19, 1 „ „	1	1	0			
„ 1919-20, 6 „ „	6	6	0			
„ 1920-21, 19 „ „	19	19	0			
Subscriptions :— 1913-14, 1 at £2 2s. 0d.	2	2	0			
„ 1914-15, 1 „ „	2	2	0			
„ 1915-16, 2 „ „	4	4	0			
„ 1916-17, 1 „ „	2	2	0			
„ 1917-18, 2 „ „	4	4	0			
„ 1918-19, 5 „ „	10	10	0			
„ 1919-20, 11 „ „	23	2	0			
„ 1920-21, 274 „ „	575	8	0			
„ 1921-22, 1 „ „	2	0	0			
				658	7	0
To Sale of Publications :—						
Memoirs and Proceedings	8	9	3			
Catalogues	0	14	3			
				9	3	6
To Manchester Museum, 450 Halkyard Memoirs...				38	0	0
To Sale of Duplicate Volumes				13	15	0
To Transfers from Wilde Endowment Fund :—						
Rent of Rooms	50	0	0			
Entrance Fees	12	12	0			
Half Subscriptions	21	0	0			
				83	12	0
To Dividends :—						
Natural History Fund	42	17	6			
Joule Memorial Fund	13	2	9			
Wilde Endowment Fund	1	15	0			
				57	15	3
To Bank Interest				0	15	10
To Expenses of Meetings :—						
Institute of Chemistry (Manchester Section)...	1	10	0			
Lancashire and Cheshire Antiquarian Society	1	0	0			
Manchester and Salford Sanitary Association...	1	10	0			
„ Astronomical Society	9	0	0			
„ Microscopical Society	20	0	0			
„ Statistical Society	4	0	0			
Society of Chemical Industry (Manchester Section)	1	0	0			
				38	0	0
To National Health Insurance Act deductions ...				1	16	8
To Unemployed Act deductions				0	11	8
				£966	16	5

AND PHILOSOPHICAL SOCIETY.

Society, from 1st April, 1920, to 31st March, 1921. Cr.

	£	s.	d.	£	s.	d.
By Charges on Property :—						
Chief Rent	9	0	10			
Income Tax and Inhabited House Duty ...	3	17	4			
Insurance against Fire	11	0	0			
				23	18	2
By House Expenditure :—						
Coal, Gas, Electric Light, Water, etc.	83	1	6			
Tea, Coffee, etc., at Meetings	34	19	6½			
Cleaning, Washing, etc.	9	4	6			
Replacements	11	9	9			
Repairs, etc.	24	3	3			
Chairs Re-seated	2	5	0			
Clock Cleaned	0	17	6			
Dalton Relics Framed, etc.	0	16	6			
Notice Board, etc.	2	11	4			
				169	8	10½
By Administrative Charges :—						
Assistant Secretary's Salary	141	13	4			
Caretaker and Housekeeper	122	15	0			
Servant	26	0	0			
Extra Attendance at Meetings	13	14	0			
" " Weekly	19	8	0			
Postages, Carriage of Parcels, "Memoirs" ...	41	7	6½			
Stationery, Cheques, Receipts, Engrossing, etc.	31	3	6			
Insurance against Liability	1	9	7			
National Health Insurance Stamps	3	15	4			
Unemployment " "	1	4	2			
Miscellaneous Expenses	5	18	9			
				408	9	2½
By Publishing :—						
Printing "Memoirs and Proceedings," and Illustrations, Circulars, etc.				242	1	10
By Library :—						
Periodicals (except those charged to Natural History Fund)				16	9	5
By Advertising Duplicate Volumes				3	4	6
By Post Office Telephone				9	12	0
By Bank Interest on Overdraft				0	0	11
By Natural History Fund :—						
(Items shown in Balance Sheet of this Fund)				23	3	3
By Wilde Endowment Fund :—						
Dividend Refunded (War Loan)				1	15	0
By Extension and Alterations :—						
Common Room Furniture	40	13	0			
Postages, Typing, etc.	3	15	11			
				44	8	11
By Balance* at Williams Deacon's Bank, 1st April, 1921	14	4	4			
By Balance in Treasurer's Hands	10	0	0			
				24	4	4
				£966	16	5

* This Fund is also debtor to the Wilde Endowment Fund to the extent of £381. 19s. 0d.; to the Joule Memorial Fund, £121. 14s. 9d.; to the Natural History Fund, £181. 17s. 6d.; and to the Building Fund, £36. 1s. 1d. Total, £721. 12s. 4d.

JOULE MEMORIAL FUND, 1920-1921. (Included in the General Account, above.)

Dr.		£ s. d.
To Balance, due to this Fund from the General Fund, 1st April, 1920		108 12 0
To Dividends :—		
Dividend on £100 East India Railway Company's 4% Annuity Stock	4 7 9	
Interest on £250 5% War Loan Stock	8 15 0	
		13 2 9
		£121 14 9

Cr.	£ s. d.
By Balance,* due to this Fund from the General Fund, 1st April, 1921	121 14 9
	£121 14 9

*1st Joule Memorial Lecture : Honorarium was returned by the Lecturer.

NATURAL HISTORY FUND, 1920-21. (Included in the General Account, above.)

Dr.		£ s. d.
To Balance, due to this Fund from the General Fund, 1st April, 1920		162 3 3
To Dividends on £1,225 Great Western Railway Company's Stock		42 17 6
		£205 0 9

Cr.		£ s. d.
By Natural History Periodicals		14 0 1
By Subscriptions :—		
Lancashire & Cheshire Fauna Committee, 1920	1 1 0	
Palæontographical Society, 1918	1 1 0	
		2 2 0
By Illustrations, Natural History Memoirs		4 11 11
By Binding Natural History Periodicals		2 9 3
To Balance, due to this Fund from the General Fund, 1st April, 1921		181 17 6
		£205 0 9

WILDE ENDOWMENT FUND, 1920-21.

Dr.	£ s. d.
To Balance, due to this Fund from the General Fund, 1st April, 1920	381 19 0
To Dividends on £7,500 Gas Light and Coke Company's Ordinary Stock	157 10 0
To Interest on £50 5% War Loan Stock	1 15 0
To Bank Interest	0 11 0
To Overdraft at Williams Deacon's Bank, 1st April, 1921	117 15 11
	£659 10 11

Cr.		£ s. d.
By Overdraft at Williams Deacon's Bank, 1st April, 1920		18 3 9
By Assistant Secretary's Salary		150 0 0
By Maintenance of Society's Library :—		
Binding Books		24 17 9
By Transfer to Society's Funds :—		
Rent of Rooms	50 0 0	
Entrance Fees	12 12 0	
Half Subscriptions	21 0 0	
		83 12 0
By Bank Interest on Overdraft		0 14 3
By Cheque Book		0 4 2
By Balance, due to this Fund from the General Fund, 1st April, 1921		381 19 0
		£659 10 11

Dr. BUILDING FUND, 1919-20. *Cr.*

	£	s.	d.		£	s.	d.
To Donations (credited to General Fund)	120	0	0	By Common Room Decorations (see General Fund) ...	39	10	0
				By Balance, due to this Fund from the General Fund, 1st April, 1920	80	10	0
	£120	0	0		£120	0	0

BUILDING FUND, 1920-1921.

	£	s.	d.		£	s.	d.
By Balance, due to this Fund from the General Fund, 1st April, 1920	80	10	0	By Purchase of Property, 21 and 21A, Back George Street...	1069	7	1
To Donations	1135	5	8	By Common Room Furniture	189	3	6
To Bank Interest	11	16	5	By Cloak Room Alterations	2	0	10
To Overdraft at Williams Deacon's Bank, 1st April, 1921	120	0	8	By Printing	5	19	6
				By Bank Interest on Overdraft	0	7	8
				By Cheque Book	0	4	2
				By Furniture, etc. (see General Fund, 1920-21)	44	8	11
				By Balance due to this Fund from the General Fund, 1st April, 1921	36	1	1
	£1347	12	9		£1347	12	9

Statement relating to Society's Property as on 31st March, 1921.

LIABILITIES.

		£ s. d.
Sundry Creditors :—		
General Fund	51 6 6	
Building Fund	172 5 0	
German Periodicals (approximately)	25 0 0	
		248 11 6
Bank Overdrafts :—		
Wilde Endowment Fund	117 15 11	
Building Fund	120 0 8	
		237 16 7
Printing :—		
Memoirs and Proceedings :		
Vol. 63, No. 5 and Proc.	approximately	150 0 0
Vol. 64, Nos. 1, 2 and Proc.		
In Press, Vol. 64, Nos. 4 and 5 and Proc.		
Vol. 65, Nos. 1—		
		£636 8 1

German Periodicals, since July 1914, required.
There are 3 Life Composition Fees.

ASSETS.

		£ s. d.
Arrears of Subscriptions, 1920-21 (estimated to produce)	73 10 0	
Arrears of Subscriptions, earlier (estimated to produce)	26 5 0	
		99 15 0
Income Tax (recoverable) for 1918-20 :—		
Joule Memorial Fund	11 11 7	
Natural History Fund	36 15 0	
Wilde Endowment Fund	141 0 0	
		189 6 7
Income Tax (recoverable) October 1920—March 31st, 1921 (Approximate)		69 0 0
Dividends for ¼th year ended March 31st, 1921 (Aproximate)		54 13 3
Appeal Fund, donations promised		102 15 10
Expenses of Meetings		4 0 0
Sale of Publications (estimate)		5 0 0
„ Duplicate volumes	28 6 10	
„ „ „ unsold (estimate)...	20 0 0	
		48 6 10
Cash balance :—		
In Bank (General Fund)	14 4 4	
In Treasurer's Hands	10 0 0	
		24 4 4
		£597 1 10

Investments :—
£7,500 Gas Light and Coke Company's Ordinary Stock (W.E.F.) ... ...
£1,225 Great Western Railway Company's 5% Consolidated Preference Stock (Nat. Hist. F.) ... ...
£100 East India Railway Company's 4% Annuity Stock (J.M.F.) ... ...
£250 5% War Loan Stock, 1929-47 (J.M.F.) ... ...
£50 „ „ „ „ „ (W.E.F.) ... ...
Society's Premises, Furniture, Library, Collections, Stock of Unsold Publications, and New Premises, 21 and 21A, Back George Street.

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OF THE
MANCHESTER LITERARY AND PHILOSOPHICAL SOCIETY.

1920-21.

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Assistant Secretary and Librarian.
R. F. HINSON.

THE WILDE LECTURES.

1897. (July 2.) "On the Nature of the Röntgen Rays." By Sir G. G. STOKES, Bart., F.R.S. (28 pp.)

1898. (Mar. 29.) "On the Physical Basis of Psychical Events." By Sir MICHAEL FOSTER, K.C.B., F.R.S. (46 pp.)

1899. (Mar. 28.) "The newly discovered Elements; and their relation to the Kinetic Theory of Gases." By Professor WILLIAM RAMSAY, F.R.S. (19 pp.)

1900. (Feb. 13.) "The Mechanical Principles of Flight." By the Rt. Hon. LORD RAYLEIGH, F.R.S. (26 pp.)

1901. (April 22.) "Sur la Flore du Corps Humain." By Dr. ELIE METSCHNIKOFF, For.Mem.R.S. (38 pp.)

1902. (Feb. 25.) "On the Evolution of the Mental Faculties in relation to some Fundamental Principles of Motion." By Dr. HENRY WILDE, F.R.S. (34 pp., 3 pls.)

1903. (May 19.) "The Atomic Theory." By Professor F. W. CLARKE, D.Sc. (32 pp.)

1904. (Feb. 23.) "The Evolution of Matter as revealed by the Radio-active Elements." By FREDERICK SODDY, M.A. (42 pp.)

1905. (Feb. 28.) "The Early History of Seed-bearing Plants, as recorded in the Carboniferous Flora." Dr. D. H. SCOTT, F.R.S. (32 pp., 3 pls.)

1906. (March 20.) "Total Solar Eclipses." By Professor H. H. TURNER, D.Sc., F.R.S. (32 pp.)

1907. (Feb. 18.) "The Structure of Metals." By Dr. J. A. EWING, F.R.S., M.Inst.C.E. (20 pp., 5 pls., 5 text-figs.)

1908. (March 3.) "On the Physical Aspect of the Atomic Theory." By Professor J. LARMOR, Sec.R.S. (54 pp.)

1909. (March 9.) "On the Influence of Moisture on Chemical Change in Gases." By Dr. H. BRERETON BAKER, F.R.S. (8 pp.)

1910. (March 22.) "Recent Contributions to Theories regarding the Internal Structure of the Earth." By Sir THOMAS H. HOLLAND, K.C.I.E., D.Sc., F.R.S.

SPECIAL LECTURES.

1913. (March 4.) "The Plant and the Soil." By A. D. HALL, M.A., F.R.S.

1914. (March 18.) "Crystalline Structure as revealed by X-rays." By Professor W. H. BRAGG, M.A., F.R.S.

1915. (May 4.) "The Place of Science in History." By Professor JULIUS MACLEOD, D.Sc.

JOULE MEMORIAL LECTURE.

1920. (Dec. 14.) "The Work and Discoveries of Joule." By Sir DUGALD CLERK, K.B.E., D.Sc., F.R.S.

Awards of the Dalton Medal.

1898. EDWARD SCHUNCK, Ph.D., F.R.S.

1900. Sir HENRY E. ROSCOE, F.R.S.

1903. Prof. OSBORNE REYNOLDS, LL.D., F.R.S.

1919. Prof. Sir ERNEST RUTHERFORD, M.A., D.Sc., F.R.S.

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1782-1786.	JAMES MASSEY, THOMAS PERCIVAL, M.D., F.R.S.
1787-1789.	JAMES MASSEY.
1789-1804.	THOMAS PERCIVAL, M.D., F.R.S.
1805-1806.	Rev. GEORGE WALKER, F.R.S.
1807-1809.	THOMAS HENRY, F.R.S.
1809.	*JOHN HULL, M.D., F.L.S.
1809-1816.	THOMAS HENRY, F.R.S.
1816-1844.	JOHN DALTON, D.C.L., F.R.S.
1844-1847.	EDWARD HOLME, M.D., F.L.S.
1848-1850.	EATON HODGKINSON, F.R.S., F.G.S.
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1855-1859.	Sir WILLIAM FAIRBAIRN, Bart., LL.D., F.R.S.
1860-1861.	JAMES PRESCOTT JOULE, D.C.L., F.R.S.
1862-1863.	EDWARD WILLIAM BINNEY, F.R.S., F.G.S.
1864-1865.	ROBERT ANGUS SMITH, Ph.D., F.R.S.
1866-1867.	EDWARD SCHUNCK, Ph.D., F.R.S.
1868-1869.	JAMES PRESCOTT JOULE, D.C.L., F.R.S.
1870-1871.	EDWARD WILLIAM BINNEY, F.R.S., F.G.S.
1872-1873.	JAMES PRESCOTT JOULE, D.C.L., F.R.S.
1874-1875.	EDWARD SCHUNCK, Ph.D., F.R.S.
1876-1877.	EDWARD WILLIAM BINNEY, F.R.S., F.G.S.
1878-1879.	JAMES PRESCOTT JOULE, D.C.L., F.R.S.
1880-1881.	EDWARD WILLIAM BINNEY, F.R.S., F.G.S.
1882-1883.	Sir HENRY ENFIELD ROSCOE, D.C.L., F.R.S.
1884-1885.	WILLIAM CRAWFORD WILLIAMSON, LL.D., F.R.S.
1886.	ROBERT DUKINFIELD DARBISHIRE, B.A., F.G.S.

* Elected April 28th; resigned office May 5th.

Date of Election.	
1887.	BALFOUR STEWART, LL.D., F.R.S.
1888-1889.	OSBORNE REYNOLDS, LL.D., F.R.S.
1890-1891.	EDWARD SCHUNCK, Ph.D., F.R.S.
1892-1893.	ARTHUR SCHUSTER, Ph.D., F.R.S.
1894-1896.	HENRY WILDE, D.C.L., F.R.S.
1896.	EDWARD SCHUNCK, Ph.D., F.R.S.
1897-1899.	JAMES COSMO MELVILL, M.A., F.L.S.
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1907-1909.	HAROLD BAILY DIXON, M.A., F.R.S.
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1919.	G. ELLIOT SMITH, M.A., M.D., F.R.S.
1919-1921.	Sir HENRY A. MIERS, M.A., D.Sc., F.R.S.
1921-	T. A. COWARD, M.Sc., F.Z.S., F.E.S.